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THE EFFECT OF HAVING ROWS DIFFERENT DISTANCES APART IN ROD ROW PLOT TESTS OF WHEAT, OATS AND BARLEY[1]

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Breeders of small grains require accurate comparative plot tests of the promising selections or hybrids. It is highly desirable that such tests be made as soon as possible after hybrids are sufficiently uniform to be considered as new varieties. The seed from a plant progeny row is insufficient for a standard replicated rod row test wherein several rows from 6 to 12 inches apart must be used for each plot. However, a row from 5 to 8 feet long usually furnishes sufficient seed for a replicated single row test. Love and Craig (5) found that single rod row plots with the rows 12 inches apart gave results satisfactorily free from competition distortion in the case of closely related lines at Ithaca, New York. On the other hand Kiesselback (4) discovered distinct competitive effects extending fully 12 inches in rod row tests of small grains varieties.

In order to have a 4 to 6 replicate comparative plot test of new purified hybrids practically free from competition and yet without delaying a year to increase the plant progeny rows, the writer commenced in 1933 the use of single row plots with the rows 18 inches apart. This procedure was designated as the EE test. The amount of seed sown is the same as for rows 12 inches apart, that is, twice the normal drill-run rate for rows 6 inches apart. The EE test allows competition to be reduced to a minimum by the 18 inch space between rows, and the small amount of seed available is used efficiently since none of it goes into borders. We have used the new plot for preliminary line tests in wheat, oats and barley continuously since 1933. Observational study indicated the method to be sound.

From the first it was desired to make a comprehensive trial of the new method compared with the use of rows 6 inches apart and 12 inches apart. The standard cereal yield plot at many experiment stations in Canada consists of five rows 6 or 7 inches apart of which the centre three are harvested. The standard cereal yield plot at a large proportion of the stations in Canada and the United States consists of three rows 12 inches apart of which the centre one is harvested and the other two rows are considered as borders.

In general no significant differences have been found between results obtained from rows 6 inches apart and those from rows 12 inches apart. Jodon and Beachell in 1936 (3) tested four varieties of rice in plots with

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rows 6, 8, 10 and 12 inches apart at four rates of seeding at two stations. They found that no interactions were significant at either station which indicated that the varietal differences were unaffected by the differences in row spacings and seeding rates. Dillman and Brinsmade (2) studied two flax varieties in 6 and 12 inch row spacings for four years. There was no varietal-spacing interaction for yield excepting in 1929 and then it appeared to be significant.

However rows 18 inches apart are much more different from the farmers 6 or 7 inches than are rows 12 inches apart and a careful study of their value in cereal work appeared necessary.

MATERIALS AND METHODS

In 1936 a four-year test was commenced in which two highly contrasted varieties of each of three crops were tested comparably at each of three row spacings.

The varieties selected were Marquis and Reward wheat, Banner and Gopher oats and Regal and Hannchen barley. Marquis and Reward differ decidedly in time of maturity, in response to different rates and dates of sowing and in yield response in various seasons. Gopher and Banner represent different types of oats one being the early fine strawed thin hulled type and the other the mid-late, coarser strawed, heavier hulled type. They yield differently according to the season and conditions. Hannchen and Regal likewise are extremes in type, the former being two-rowed, short strawed, fairly late and high in drought resistance while Regal is six-rowed, taller, earlier and less drought resistant but better able than Hannchen to take advantage of certain favourable growth conditions. It was expected that these pairs of varieties would reveal in their responses to the different spacings the suitability of the 18-inch spacing for preliminary strain tests.

The row spacings were 6 inches, 12 inches and 18 inches. The plot for the 6 inch test consisted of six rows 6 inches apart sown at the usual farm rate. Notes and yields were taken on the centre two rows. The 12-inch plot consisted of three rows 12 inches apart of which the centre row only was used for notes and yield. The EE plots consisted of single rows 18 inches apart. The seeding rate for the rows 12 inches and 18 inches apart was double that used in the 6-inch rows. All rows were sown $18\frac{1}{2}$ feet long and the central $16\frac{1}{2}$ feet was harvested for yield.

The experiment was arranged as a split-plot 6 $\times$ 6 latin square as shown in Figure 1. Each of the 36 main plots was split into three sub-plots for the three row spacings. Figure 2 gives the detail of the sub-plot arrangement. This method provided close comparison of the three spacings, accurate comparisons of varieties or crops, and a satisfactory check on variety-spacing interaction in each crop. At the same time the plan necessitated a minimum of fillers between plots. Figures 1 and 2 show the general plan and the detail of sub-plots. A discussion of the variance analysis of a somewhat similar split-plot test was published recently by Wishart (6).

In comparing the use of the three different row spacings there is one paramount question to be answered. Does the use of rows 18 inches apart lead the breeder to draw the same conclusions as to the *relative*

merits of lines as would the use of rows 12 inches or 6 inches apart? If so the EE test is sound. If not, the nature and extent of the discrepancies would have to be examined to determine the limitations of the EE method.

The years during which this study was conducted differed markedly in many particulars but on the whole favoured early varieties. This was shown in both wheat and oats where the contrasted varieties differed four or five days in time of maturity. Throughout the four-year period

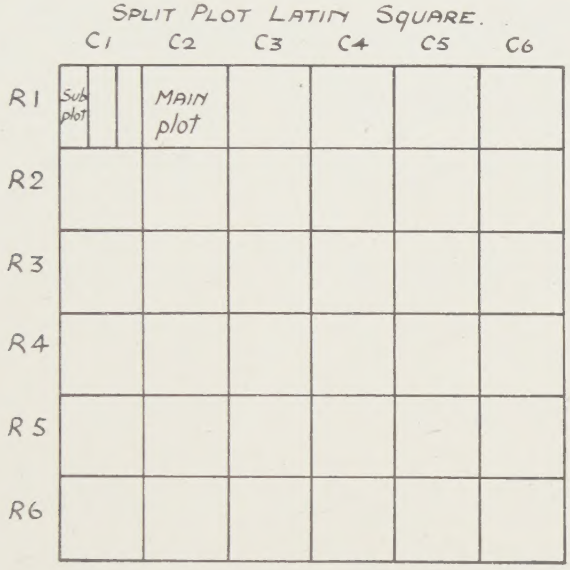

FIGURE 1. The experiment was arranged each year in the form of a triple split plot 6 × 6 latin square.

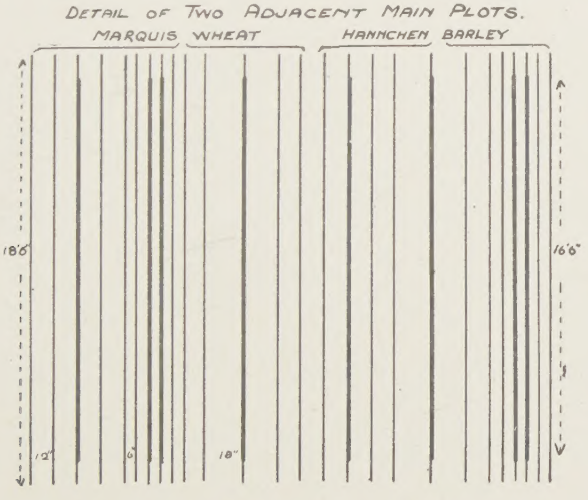

FIGURE 2. The three types of rod row plots were randomized within each main plot with special buffer rows added to guard against competitive effects. The heavy parts of the lines for the centre rows represent the portions used for note taking and yield determinations.

TABLE 1.—PLOT ARRANGEMENT AND INDIVIDUAL PLOT YIELDS IN GRAMS FOR EACH OF THE FOUR YEARS

	Column 1			Column 2			Column 3			Column 4			Column 5			Column 6		
1936																		
Row 1	206	194	176	144	150	155	246	212	235	131	192	167	204	143	164	234	217	229
	G6	G12	G18	M18	M12	M6	H6	H12	H18	B18	B6	B12	Rw6	Rw18	Rw12	Rg12	Rg18	Rg6
Row 2	267	302	270	194	188	158	179	195	117	163	176	147	307	263	284	186	180	123
	Rg18	Rg6	Rg12	Rw6	Rw12	Rw18	B12	B6	B18	G6	G12	G18	H6	H18	H12	M12	M6	M18
Row 3	214	125	165	283	233	261	129	122	200	207	212	240	153	190	149	180	169	166
	B6	B18	B12	Rg12	Rg18	Rg6	G18	G12	G6	H18	H12	H6	M12	M6	M18	Rw6	Rw18	Rw12
Row 4	236	206	244	185	186	121	152	129	154	119	132	119	223	222	229	132	105	121
	H12	H18	H6	B12	B 6	B18	Rw12	Rw18	Rw6	M18	M12	M6	Rg12	Rg18	Rg6	G12	G6	G18
Row 5	156	147	130	148	136	136	233	215	246	179	136	120	117	123	135	169	168	185
	M18	M6	M12	G18	G12	G6	Rg18	Rg12	Rg6	Rw6	Rw12	Rw18	B18	B12	B6	H6	H18	H12
Row 6	235	204	203	325	294	274	185	157	139	230	244	207	142	135	147	115	142	141
	Rw6	Rw12	Rw18	H6	H12	H18	M6	M12	M18	Rg12	Rg6	Rg18	G12	G18	G6	B12	B6	B18
1937																		
Row 1	105	99	97	68	90	38	126	86	101	69	11	33	68	54	79	92	116	96
	M6	M18	M12	B12	B18	B6	G18	G6	G12	Rg18	Rg6	Rg12	H12	H6	H18	Rw12	Rw6	Rw18
Row 2	97	84	37	62	84	107	80	74	68	57	61	61	26	40	27	4	16	35
	H18	H12	H6	G6	G12	G18	Rw12	Rw6	Rw18	M6	M18	M12	B12	B18	B6	Rg6	Rg12	Rg18
Row 3	31	52	21	48	22	46	65	76	64	64	69	74	1	3	35	89	78	97
	B12	B18	B6	H12	H6	H18	M6	M12	M18	Rw12	Rw18	Rw6	Rg6	Rg12	Rg18	G12	G6	G18
Row 4	105	81	101	88	70	72	7	17	2	8	21	62	79	92	100	74	45	46
	G18	G6	G12	M6	M18	M12	Rg12	Rg18	Rg6	B6	B12	B18	Rw12	Rw18	Rw6	H18	H12	H6
Row 5	59	67	62	18	9	3	48	24	68	99	112	89	94	90	81	72	93	60
	Rw12	Rw18	Rw6	Rg18	Rg12	Rg6	H12	H6	H18	G12	G18	G6	M6	M18	M12	B12	B18	B6
Row 6	44	49	54	95	103	109	44	78	84	57	70	46	73	71	85	62	71	71
	Rg6	Rg18	Rg12	Rw18	Rw12	Rw6	B6	B12	B18	H6	H18	H12	G6	G12	G18	M12	M18	M6

Abbreviations: M=Marquis, Rw=Reward, B=Banner, G=Gopher, Rg=Regal, H=Hannchen, 6=6-inch spacing, 12=12-inch spacing, 18=18-inch spacing.

TABLE 1.—PLOT ARRANGEMENT AND INDIVIDUAL PLOT YIELDS IN GRAMS FOR EACH OF THE FOUR YEARS—*Concluded*

	Column 1			Column 2			Column 3			Column 4			Column 5			Column 6		
							1938											
Row 1	149	164	172	177	171	177	183	177	199	10	144	81	163	153	110	125	121	119
	Rw18	Rw12	Rw6	G18	G6	G12	B12	B6	B18	Rg6	Rg18	Rg12	H18	H12	H6	M18	M12	M6
Row 2	140	151	126	38	83	125	143	173	165	155	177	120	180	198	212	194	171	168
	M6	M18	M12	Rg6	Rg12	Rg18	H6	H12	H18	B12	B18	B6	G6	G12	G18	Rw18	Rw6	Rw12
Row 3	239	232	238	195	223	236	145	162	137	187	157	163	146	229	140	118	176	169
	G18	G6	G12	H18	H12	H6	M18	M6	M12	Rw6	Rw18	Rw12	Rg6	Rg18	Rg12	B6	B12	B18
Row 4	244	199	227	197	187	177	253	68	143	162	152	153	186	186	146	178	170	169
	H12	H18	H6	Rw6	Rw12	Rw18	Rg18	Rg6	Rg12	M18	M12	M6	B12	B18	B6	G12	G6	G18
Row 5	209	193	152	140	158	164	252	262	251	192	139	95	165	147	172	50	125	89
	B12	B18	B6	M6	M12	M18	G12	G6	G18	H18	H12	H6	Rw6	Rw18	Rw12	Rg6	Rg18	Rg12
Row 6	289	202	112	232	254	246	188	153	167	172	210	223	163	160	138	198	154	177
	Rg18	Rg12	Rg6	B18	B6	B12	Rw6	Rw18	Rw12	G6	G12	G18	M12	M18	M6	H12	H6	H18
							1939											
Row 1	506	445	365	397	533	230	718	559	640	624	466	565	450	442	529	564	544	511
	Rw6	Rw18	Rw12	H12	H18	H6	Rg6	Rg18	Rg12	B12	B18	B6	M18	M12	M6	G12	G6	G18
Row 2	381	394	415	457	559	627	400	483	516	573	667	603	532	499	550	420	428	394
	G12	G6	G18	Rg12	Rg18	Rg6	Rw18	Rw6	Rw12	H12	H6	H18	B6	B18	B12	M18	M12	M6
Row 3	581	625	706	509	551	603	595	556	509	470	444	435	533	463	586	469	388	434
	Rg12	Rg6	Rg18	G6	G18	G12	B6	B12	B18	M6	M12	M18	H18	H12	H6	Rw6	Rw18	Rw12
Row 4	621	609	634	555	490	533	386	475	423	432	469	511	434	475	444	518	500	396
	H6	H12	H18	B18	B12	B6	M18	M6	M12	Rw18	Rw12	Rw6	G12	G6	G18	Rg18	Rg6	Rg12
Row 5	340	361	373	418	495	469	523	519	556	525	452	487	447	473	567	360	441	434
	M18	M6	M12	Rw18	Rw6	Rw12	H6	H18	H12	G6	G12	G18	Rg12	Rg6	Rg18	B12	B6	B18
Row 6	240	278	401	376	385	381	479	424	478	569	542	581	497	518	545	457	591	534
	B18	B6	B12	M6	M18	M12	G18	G6	G12	Rg12	Rg6	Rg18	Rw18	Rw12	Rw6	H6	H18	H12

Reward was higher in yield and taller than Marquis whereas the average for 1925 to 1939 shows the opposite situation. Similarly in oats Gopher averaged above Banner from 1936 to 1939 but below Banner from 1925 to 1939.

RESULTS

The study, while particularly concerned with grain yield, included complete data on time of heading, time of maturity, height of plant, strength of straw, grain grade and weight per measured bushel. The detailed results on grain yield are presented in Table 1 in the exact order in which the plots were grown.

TABLE 2.—VARIANCE ANALYSIS OF DATA FOR EACH YEAR AND FOR THE PERIOD 1936–1938

Year	Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	5% point	1% point
1936	Between means of rows	5	26836	5367	5.57	2.71	4.10
	Between means of columns	5	20337	4067	4.22	2.71	4.10
	Between means of crops	2	170773	85386	88.54	3.49	5.85
	Between means of varieties*	3	3754	1251	1.30	3.10	4.94
	Error (a)	20	19289	964			
	Main plots total	35	240989				
	Between means of spacings	2	16593	8296	28.95	3.15	4.98
	Int: spacings-crops	4	272	68	—		
	Int: spacings-varieties*	6	2343	390	1.36	2.25	3.12
	Error (b)	60	17195	287			
	Total	107	277390				
1937	Between means of rows	5	8893	1779	2.92	2.71	4.10
	Between means of columns	5	1409	282	—		
	Between means of crops	2	32688	16344	26.84	3.49	5.85
	Between means of varieties*	3	25311	8437	13.85	3.10	4.94
	Error (a)	20	12183	609			
	Main plots total	35	80484				
	Between means of spacings	2	6297	3148	39.85	3.15	4.98
	Int: spacings-crops	4	5491	1373	17.38	2.52	3.65
	Int: spacings-varieties*	6	275	46	—		
	Error (b)	60	4741	79			
	Total	107	97288				
1938	Between means of rows	5	30807	6161	2.88	2.71	4.10
	Between means of columns	5	26101	5220	2.44	2.71	4.10
	Between means of crops	2	36003	18002	8.40	3.49	5.85
	Between means of varieties*	3	31634	10545	4.92	3.10	4.94
	Error (a)	20	42835	2142			
	Main plots total	35	167380				
	Between means of spacings	2	16890	8445	23.47	3.15	4.98
	Int: spacings-crops	4	18564	4641	12.90	2.52	3.65
	Int: spacings-varieties*	6	18935	3156	8.77	2.25	3.12
	Error (b)	60	21590	360			
	Total	107	243359				
1939	Between means of rows	5	62373	12475	—		
	Between means of columns	5	61525	12305	—		
	Between means of crops	2	207241	103620	6.90	3.49	5.85
	Between means of varieties*	3	25304	8435	5.62	3.10	4.94
	Error (a)	20	300331	15017			
	Main plots total	35	656774				
	Between means of spacings	2	6086	3043	1.17	3.15	4.98
	Int: spacings-crops	4	33381	8345	3.22	2.52	3.65
	Int: spacings-varieties*	6	14775	2462	—		
	Error (b)	60	155499	2592			
	Total	107	866515				

* Varieties within crops.

TABLE 2.—VARIANCE ANALYSIS OF DATA FOR EACH YEAR AND FOR THE PERIOD 1936–1938 —*Concluded*

Year	Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	5% point	5% point
1936–38	Between means of rows	15	66536	4436	3.58	1.92	2.50
	Between means of columns	15	47847	3190	2.58	1.92	2.50
	Between means of crops	2	6888	3444	2.78	3.15	4.98
	Between means of varieties*	3	38777	12926	10.44	2.76	4.13
	Between means of years	2	930167	465084	375.67	3.15	4.98
	Int: crops-years	4	232577	58144	46.97	2.52	3.65
	Int: varieties-years	6	21922	3654	2.95	2.25	3.12
	Error (a)	60	74308	1238			
	Main plots total	107	1419022				
	Between means of spacing	2	2049	1024	4.23	3.04	4.71
	Int: spacings-crops	4	14079	3520	14.55	2.42	3.41
	Int: spacings-varieties*	6	6995	1166	4.82	2.14	2.89
	Int: spacings-years	4	37731	9433	38.98	2.42	3.41
	Int: spacing-crops-years	8	10249	1281	5.29	1.98	2.60
	Int: spacing-varieties-years	12	14557	1213	5.01	1.80	2.28
	Error (b)	180	43524	242			
	Total	323	1548206				

* Varieties within crops.

The variance analysis of grain yield for each year of the study is given in Table 2. Highly significant differences between crops occurred every year. Highly significant differences between varieties within crops occurred in every year excepting 1936 when the differences proved unimportant. Differences between spacings were highly significant in every year excepting 1939. The interaction between spacings and crops was highly significant in 1937 and 1938, significant in 1939 and of no importance in 1936. The main purpose of the study was to obtain information on the interaction of spacings with varieties within crops. This was of negligible importance in 1936, 1937 and 1939 but was highly significant in 1938.

In addition to the analysis of the data for each year it was considered desirable to make a variance analysis of the entire yield results for the four-year period. However the study was less precise in 1939 than in the other years as indicated by the significantly larger mean squares for errors *(a)* and *(b)* in 1939. Consequently tests of significance based on a four year analysis would not be strictly valid[1]. However, a combined analysis for the years 1936, 1937 and 1938 appears to be legitimate as there is reasonable homogeneity of intra-class variance. The combined variance analysis is shown at the end of Table 2. Crop differences, although highly significant each year were not significant for the three-year period. On the other hand, variety differences within crops were very significant. Year differences and all the first and second order interactions involving years were highly significant. The very important interaction of spacings with varieties was highly significant although in each individual year excepting 1938 it was unimportant. The spacings × crops interaction was also very significant.

[1] This point was elucidated recently by Yates and Cochran (7) in connection with analysing groups of experiments and by Cochran (1) in his review of difficulties encountered in the analysis of replicated experiments.

TABLE 3.—THE VARIANCE ANALYSIS OF THE DATA ON EACH OF THE THREE CROPS FOR EACH YEAR

Year	Source of variation	Deg. of freedom	Wheat		Oats		Barley	
			Sum of squares	Mean square	Sum of squares	Mean square	Sum of squares	Mean square
1936	Between means of replicates	5	10976	2195	9236	1847	23837	4767
	Between means of varieties	1	3681	3681	34	34	40	40
	Error (a)	5	2507	501	5114	1023	14792	2958
	Main plots total	11	17164		14384		38669	
	Between means pf spacings	2	5725	2862	7133	3566	4009	2004
	Int:—spacings-varieties	2	299	150	1907	954	135	68
	Error (b)	20	4696	235	8760	438	3737	187
	Total	35	27884		32184		46550	
1937	Between means of replicates	5	4770	954	4805	961	4574	915
	Between means of varieties	1	368	368	14843	14843	10100	10100
	Error (a)	5	2979	596	3401	680	1956	391
	Main plots total	11	8117		23049		16630	
	Between means of spacings	2	375	188	6228	3114	5185	2592
	Int:—spacings-varieties	2	35	18	154	77	86	43
	Error (b)	20	870	44	1403	70	2468	123
	Total	35	9397		30834		24369	
1938	Between means of replicates	5	2743	549	15323	3065	51660	10332
	Between means of varieties	1	5929	5929	5208	5208	20496	20496
	Error (a)	5	1296	259	18353	3671	10368	2074
	Main plots total	11	9968		38884		82524	
	Between means fo spacings	2	146	73	3872	1936	31435	15718
	Int:—spacings-varieties	2	1053	526	728	364	17156	8578
	Error (b)	20	2540	127	4454	223	14595	730
	Total	35	13707		47938		145710	
1939	Between means of replicates	5	8346	1669	122512	24502	27912	5582
	Between means of varieties	1	19976	19976	49	49	5281	5281
	Error (a)	5	34193	6839	78401	15680	152864	30573
	Main plots total	11	62515		200962		186057	
	Between means of spacings	2	16017	8008	4125	2062	19326	9663
	Int:—spacings-varieties	2	2400	1200	3614	1807	8760	4380
	Error (b)	20	19894	995	42452	2123	93153	4658
	Total	35	100826		251153		307296	
1936–38	Between means of replicates	15	18489	1233	29364	1958	80071	5338
	Between means of varieties	1	8199	8199	11802	11802	18776	18776
	Between means of years	2	151608	75804	281138	140569	729999	364444
	Int:—Varieties-years	2	1777	888	8283	4142	11860	5930
	Error (a)	15	6780	452	26868	1791	27116	1808
	Main plots total	35	186853		357455		867822	
	Between means of spacings	2	3539	1770	1107	554	11481	5470
	Int: spacings-varieties	2	950	475	187	94	5862	2931
	Int: spacings-years	4	2706	676	16126	4032	29148	7287
	Int: spa..-var.-years	4	437	109	2602	650	11515	2879
	Error (b)	60	8110	135	14618	244	20800	347
	Total	107	202595		392095		94628	

Since the main consideration in this study is the comparative behaviour at different row spacings of the varieties within a crop, the yield data were analysed separately for each crop. The analyses for each year and for the period 1936 to 1938 are presented in Tables 3 and 4.

Results with Wheat

As shown by Tables 3 and 4 Reward and Marquis differed significantly in 1936 and 1938 and for the 1936–38 period but not in 1937 or 1939.

Spacing differences were significant in 1936, 1937 and 1939 and for the period as a whole. The variety-spacing interaction was not significant in 1936, 1937 and 1939, but it was significant by odds of more than 19 to 1 in 1938 and for the period 1936–38.

TABLE 4.—THE SIGNIFICANCE OF DIFFERENCES AND INTERACTIONS AS SHOWN BY F VALUES IN RELATION TO THE 5% AND 1% POINTS AS OBTAINED FROM A SEPARATE ANALYSIS OF THE DATA ON EACH CROP

Year	Source of variation	F values Wheat	Oats	Barley	5% pt.	1% pt.
1936	Varieties	7.35	—	—	6.61	16.26
	Spacings	12.19	8.14	10.72	3.49	5.85
	Spac.-Var.	—	2.18	—	3.49	5.85
1937	Varieties	—	21.83	25.83	6.61	16.26
	Spacings	4.27	44.49	21.07	3.49	5.85
	Spac.-Var.	—	1.10	—	3.49	5.85
1938	Varieties	22.89	1.42	9.88	6.61	16.26
	Spacings	—	8.68	21.53	3.49	5.85
	Spac.-Var.	4.14	1.63	11.75	3.49	5.85
1939	Varieties	2.92	—	—	6.61	16.26
	Spacings	8.05	—	2.07	3.49	5.85
	Spac.-Var.	1.21	—	—	3.49	5.85
1936–38	Varieties	18.14	6.59	10.38	4.54	8.68
	Years	167.71	78.49	201.57	3.68	6.36
	Var.-Years	1.96	2.31	3.28	3.68	6.36
	Spacings	13.11	2.27	16.54	3.15	4.98
	Spac.-Var.	3.52	—	8.45	3.15	4.98
	Spac.—Years	5.01	16.52	21.00	2.52	3.65
	Spac.-Var.-Yrs.	—	2.66	8.30	2.52	3.65

In Table 5 the summarized results on Marquis and Reward wheat are given for each row spacing for yield, earliness, height and bushel weight. Differences between Marquis and Reward resulting from row spacing

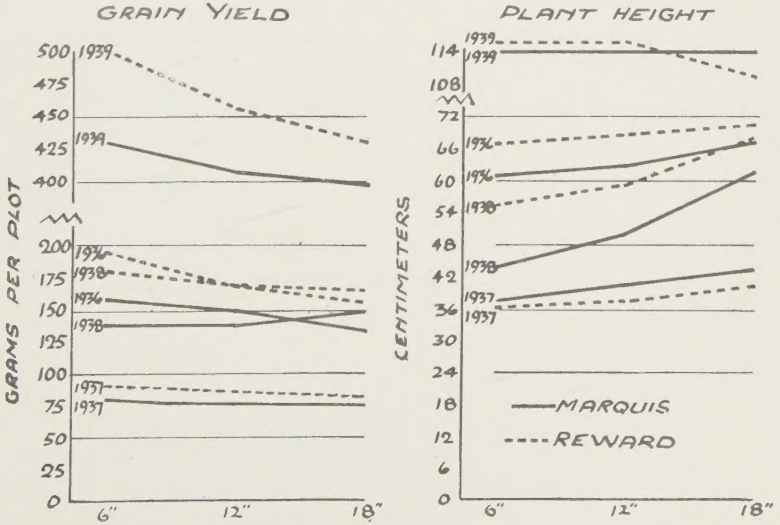

FIGURE 3. Graphical presentation of the wheat results for grain yield and plant height.

differences, were negligible for bushel weight and earliness. The same is true of height excepting in 1939 when a non-significant reversal occurred. The Reward-Marquis difference in grain yield tended to decrease with increasing row spacing, indicating that Reward was less able to utilize wide spacings than Marquis. The difference between Reward and Marquis at the 6-inch spacing was significantly different from the comparable Reward-Marquis difference at the 18-inch spacing in 1938 but not in any other year. This was to be expected since the variety-spacing interaction in 1938 proved significant. However there was no significant difference between the results for the 12-inch and 18-inch spacings in any year of the study.

TABLE 5.—SUMMARIZED RESULTS ON MARQUIS AND REWARD WHEAT AT DIFFERENT ROW SPACINGS

Year	Variety	Yield in grams per plot of 16·5 sq. ft.				Days from seeding to ripe			Height of plant in inches			Bushel weight in pounds		
		6″	12″	18″	Nec. dif.*	6″	12″	18″	6″	12″	18″	6″	12″	18″
1936	Marquis	163	151	138	17	83.7	83.5	84.8	61.0	62.5	66.8	59.8	60.0	60.0
1936	Reward	191	168	154	20	81.0	81.7	82.5	67.2	68.5	69.5	65.0	65.2	64.8
	Nec. Diff.‡	24	22	20										
1937	Marquis	80	75	76	8	90.8	91.5	91.5	36.8	39.8	43.3	62.8	63.0	63.0
1937	Reward	89	80	81	9	83.2	83.0	83.3	36.3	38.0	41.5	62.0	61.8	62.0
	Nec. Diff.‡	19	18	18										
1938	Marquis	142	143	141	12	89.5	89.8	90.3	44.8	49.5	61.7	64.8	64.8	65.0
1938	Reward	180	170	163	15	83.2	83.7	84.8	56.2	58.8	67.7	65.2	64.8	65.8
	Nec. Diff.‡	16	16	16										
1939	Marquis	434	415	403	36	102.2	103.5	103.8	115.2	115.0	114.3	63.2	63.2	63.5
1939	Reward	502	462	430	40	98.0	98.3	98.3	116.5	115.7	110.3	66.5	66.0	66.2
	Nec. Diff.‡	71	67	64										
1936–38	Marquis	128	123	122	12	88.0	88.3	88.9	47.5	50.6	57.3	62.5	62.6	62.7
1936–38	Reward	153	139	133	14	82.5	82.8	83.5	53.2	55.1	59.6	64.1	63.9	64.2
	Nec. Diff.‡	19	18	17										

* The Necessary Difference for a single year difference between row spacings was obtained by the use of the formula $\sqrt{\frac{2 \times Er\,b \text{ variance}}{\text{No. of replicates}}} \times t$ for the 5% point with 20 degrees of freedom. Example: for Marquis wheat in 1936, $\sqrt{\frac{2 \times 235}{6}} \times 2.086 = 18.46$. The Marquis yield is 92% of the mean yield of both varieties, therefore $0.92 \times 18.46 = 17$. The N.D. for the combined three year results is obtained in a similar manner, t being 2.00 for 60 D.F.

‡ The Necessary Difference for a single year difference between the two varieties at any given spacing was obtained by the use of the formula

$$\frac{\sqrt{2 \times (1/n\,Er\,a + \frac{n-1}{n}\,Er\,b)}}{\text{No. of replicates}} \times t$$

for the 5% point with $1/n\,Er\,a\,DF + \frac{n-1}{n}\,Er\,b\,DF$ (where n is the number of unit plots in each main plot.) Example: for the 6 inch spacing in 1936, $\sqrt{\frac{2(1/3 \times 501 + 2/3 \times 235)}{6}} \times 2.131 = 22$. The mean yield for the 6-inch spacing is 110% of the mean for all the spacings, therefore $1.10 \times 22 = 24$. (The D.F. for t in this case $= 1/3 \times 5 + 2/3 \times 20 = 15$.) The N.D. for the combined three years results is obtained in a similar manner, t being 2.01 for 45 D.F.

Varietal eliminations are generally based on at least two years' data. The results of the 6-inch spacing in 1936 or 1938 taken with those of either 1937 or 1939 show no significance for the Reward-Marquis difference. The 1936 and 1938 results together show significance for the 12-inch spacing as well as for the 6-inch. Also the 1936 to 1938 results collectively show Reward significantly above Marquis at both 6-inch and 12-inch. The conclusion is reached that the tendency of the 18-inch spacing to reduce the size of differences occurring at 6-inch and 12-inch would, in tests of hybrid lines, result in the retention of some lines in the EE test which might be eliminated in the others. There was no evidence indicating that lines retained in a 6-inch or 12-inch test might be discarded in the EE test.

Results with Oats

Tables 3 and 4 shows that Banner and Gopher differed significantly in 1937 but not in any other years nor for the 1936–38 period. Spacings differed significantly in 1936, 1937, and 1938 but not in 1939 or for the three years together. The variety-spacing interaction showed no significance in any year of the test.

TABLE 6.—SUMMARIZED RESULTS ON BANNER AND GOPHER OATS AT DIFFERENT ROW SPACINGS

Year	Variety	Yield in grams per plot of 16·5 sq. ft.				Days from seeding to ripe			Height in inches			Bushel weight in pounds		
		6″	12″	18″	Nec. dif.*	6″	12″	18″	6″	12″	18″	6″	12″	18″
1936	Banner	177	156	125	25	83.8	84.0	85.2	62.8	65.7	70.8	30.8	31.5	31.5
1936	Gopher	160	150	143	25	79.7	79.8	80.2	60.5	62.2	62.7	35.2	34.5	33.8
	Nec. Diff.*	34	31	27										
1937	Banner	33	49	70	7	90.0	90.0	90.0	35.7	41.0	47.7	23.2	25.2	25.8
1937	Gopher	78	91	105	13	82.5	83.0	83.0	38.7	38.5	46.7	36.0	36.8	38.2
	Nec. Diff.*	16	20	25										
1938	Banner	161	192	193	17	84.7	85.2	85.7	56.2	66.2	76.7	37.5	38.0	38.0
	Gopher	198	209	212	19	78.0	78.3	78.3	47.2	57.7	67.5	40.0	40.0	40.2
	Nec. Diff.*	43	47	48										
1939	Banner	491	497	450	56	100.0	100.7	101.2	114.7	114.7	115.8	36.0	36.2	37.0
	Gopher	478	485	481	56	94.7	95.0	95.0	105.0	106.3	105.7	40.2	39.5	39.0
	Nec. Diff.*	101	102	97										
1936–38	Banner	124	132	129	17	86.2	86.4	87.0	51.6	57.6	65.1	30.5	31.6	31.8
	Gopher	145	150	153	19	80.1	80.4	80.5	48.8	52.8	59.0	37.1	37.1	37 4
	Nec. Diff.*	31	33	33										

* See footnotes of Table 5.

In Table 6 summarized results are given on Banner and Gopher for each row spacing for yield, earliness, plant height and bushel weight. Varietal differences for earliness and bushel weight proved unimportant. Height differences resulting from row spacing were negligible excepting for a non-significant reversal which occurred in 1937. The yield difference between Banner and Gopher was non-significant in every case excepting

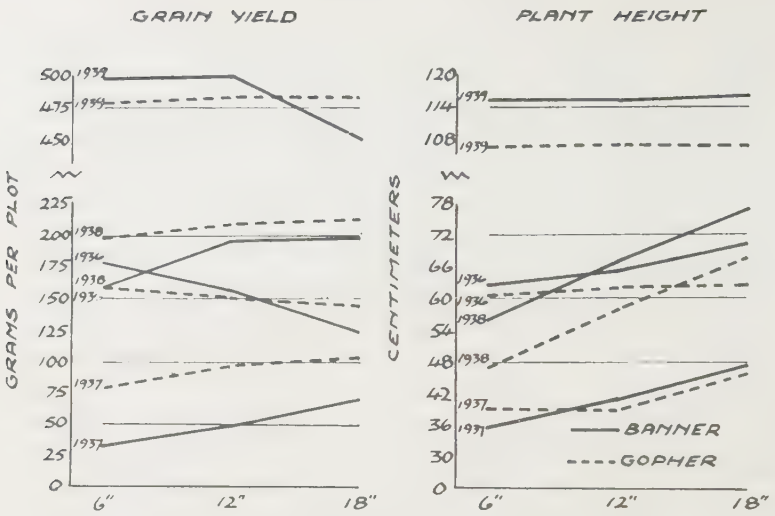

FIGURE 4. Graphical presentation of the oat results for grain yield and plant height.

in 1937 where it was significant for each spacing. The difference between the Banner-Gopher differences at 6 inch and that at 12 inch or 18 inch was not significant in 1937 or any other year.

The data may be further considered an the basis of combining the results for any two years, since varietal eliminations are seldom made on a single year's data. No combination of results from different years gives a significant variety-spacing interaction. Since the 1937 results showed significant varietal differences they were considered in connection with each of the other years' data. In no case is a significant varietal difference obtained although in the 1937–1938 combination the difference at 6 inches approaches significance.

Results with Barley

Reference to Tables 3 and 4 reveals that Regal and Hannchen differed significantly only in 1937 and 1938. Spacing differences were significant in 1936, 1937 and 1938 and in the period 1936 to 1938. The variety-spacing interaction was unimportant excepting in 1938 when it was highly significant.

The summarized results on Regal and Hannchen for each row spacing for yield, earliness, height and bushel weight are shown in Table 7. The results on earliness and the other agronomic characters, excepting yield, showed no differences of sufficient importance to consider. There were no significant varietal differences in yield due to the effects of spacings in 1936, 1939, or in the 1936–38 period taken as a whole. In 1937 the difference was not significant between the varietal differences at 6 inches and 18 inches, but in 1938 the comparable difference was significant. The difference between the 12-inch and 18-inch differences in 1938 also proved significant. This could be expected considering the highly significant variety-spacing interaction in 1938. Both the 1937 and 1938 differences at different spacings appear to be due to the fact that Hannchen

TABLE 7.—SUMMARIZED RESULTS ON REGAL AND HANNCHEN BARLEY AT DIFFERENT ROW SPACINGS

Year	Variety	Yield in grams per plot of 16·5 sq. ft.				Days from seeding to ripe			Height in inches			Bushel weight in pounds		
		6″	12″	18″	Nec. dif.*	6″	12″	18″	6″	12″	18″	6″	12″	18″
1936	Regal	252	243	230	16	79.2	79.0	79.2	55.7	58.2	62.5	41.8	43.2	44.2
1936	Hannchen	255	237	226	16	81.7	81.7	82.2	51.8	55.2	57.3	52.2	50.8	51.8
	Nec. Diff.*	43	41	39										
1937	Regal	11	20	37	8	84.0	84.0	84.0	28.0	37.3	39.3	‡	43.0	44.0
1937	Hannchen	40	57	72	18	85.8	85.8	85.8	30.5	34.8	37.0	47.5	47.8	49.2
	Nec. Diff.*	12	17	24										
1938	Regal	71	123	194	28	78.0	78.7	79.0	37.5	43.7	52.8	47.5	48.0	50.0
1938	Hannchen	161	188	182	38	79.7	80.2	20.3	33.2	40.5	44.5	52.8	55.0	55.0
	Nec. Diff.*	32	43	52										
1939	Regal	5[illegible]	515	582	80	95.0	95.7	94.8	121.3	116.7	123.3	53.5	53.8	53.2
1939	Hannchen	51[illegible]	522	569	84	95.7	95.8	96.3	109.3	107.7	111.3	52.0	53.2	53.8
	Nec. Diff.*	1[illegible]	135	149										
1936–38	Regal	111	129	154	20	80.4	80.6	80.7	40.4	46.4	51.5	44.6	44.7	46.1
	Hannchen	152	161	160	24	82.4	82.6	82.8	38.5	43.5	46.3	50.8	51.2	52.0
	Nec. Diff.*	31	34	37										

* See footnotes of Table. 5. ‡ Insufficient grain for accurate test.

resists dearth of moisture much better than Regal whereas the latter responds more fully than Hannchen to favourable conditions such as those offered by wider spacings. This was particularly evident in the extremely dry year 1937.

As yield differences in individual years are not considered a final criterion of yielding ability, the 1938 results should be examined when combined with the figures for each of the other three years. The 1939 and 1938 results taken together shows Regal and Hannchen practically equal in yield for the 6-inch spacing. But the 1938 results with either the 1936 or the 1937 figures for the 6-inch spacing show Hannchen significantly better than Regal. Actually Regal did not prove inferior to Hannchen as evidenced by the lack of significance between their yields at the 6-inch spacing for the period 1936 to 1938 taken as a whole. Therefore the discarding of Regal on the basis of the 6-inch results for two years would have been a mistake. It seems that the 1938 results were the only ones throwing doubt on the efficacy of the EE test and this discrepancy would tend to allow inferior lines to be continued rather than to allow superior lines to be discarded.

Crop Differences with Respect to Row Spacing

The summarized results on crops and spacings are given in Table 8. In 1936 yields for all crops dropped consistently with increasing spacing while plant height as consistently increased. In 1937 and 1938 the wheat yields showed no trend but both oats and barley yielded more with increasing spacing. The 1937 and 1938 heights rose very decidedly with increasing spacing. In 1939 the yield trend with increasing spacing was consistently

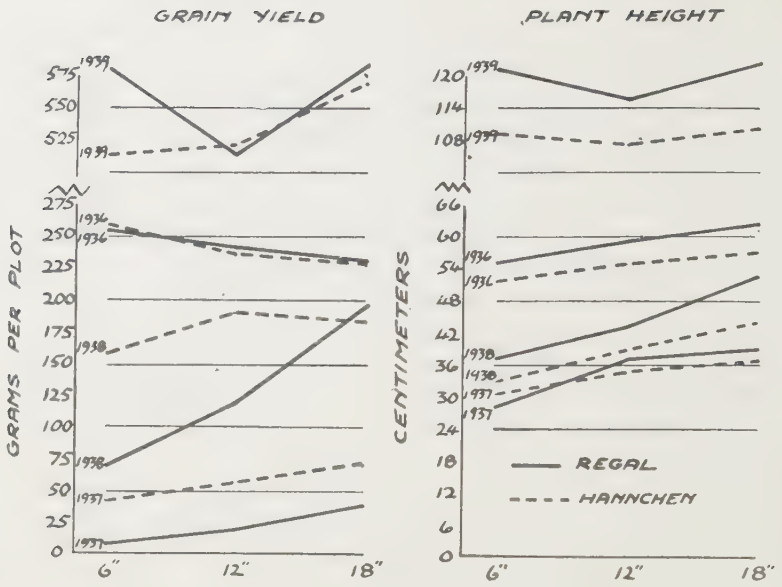

FIGURE 5. Graphical presentation of the barley results for grain yield and plant height.

down in wheat whereas in oats it was slightly down and in barley slightly up. The heights in 1939 dropped slightly in wheat but showed no trend in oats or barley.

The four-year summary shows the following facts. In wheat there was a definite downward trend of yield and an upward trend of plant height with increasing distance apart of rows. In oats no consistent yield trend for spacings occurred but in height there was a distinctly upward trend. In barley the trend with increasing row spacing was upward in height and generally upward in yield, but the latter was not as consistent as the wheat yield trend.

TABLE 8.—SUMMARIZED YIELD AND HEIGHT RESULTS ACCORDING TO CROPS AND ROW SPACINGS

Year	Mean grain yields in grams per plot								
	Wheat			Oats			Barley		
	6″	12″	18″	6″	12″	18″	6″	12″	18″
1936	177	160	146	168	153	134	254	240	228
1937	85	77	78	56	70	88	25	38	55
1938	161	156	157	180	201	202	116	156	188
1939	468	438	608	485	491	699	547	518	863
1936–38	141	131	127	135	141	141	132	145	157
1936–39	223	208	247	222	229	281	236	238	334
	Mean plant heights in centimeters								
1936	64	66	68	62	64	67	54	57	60
1937	37	39	42	37	40	47	29	36	38
1938	50	54	65	52	62	72	35	42	49
1939	116	115	112	110	110	111	115	112	117
1936–38	50	53	58	50	55	62	39	45	49
1936–39	67	68	72	65	69	74	58	62	66

DISCUSSION

Plant breeders frequently use plant and row spacings unlike those normally occurring in farmers' fields. One of the most extreme manifestations of this practice is the custom of many breeders of forage crops to make all their important selection of individual plants in such crops as grasses, clovers and alfalfa from nurseries where the plants are spaced 3 or $3\frac{1}{2}$ feet apart each way whereas under normal field conditions the plants of the same crops are only a few inches apart. Breeders of grain crops, on the other hand, have for many years considered it necessary to make their single plant selections from material grown under spacing conditions fairly closely similar to those existing in farmers' fields. The individual plants of breeding populations of such crops as wheat, oats and barley are nearly always grown in rows from 6 to 12 inches apart with the plants spaced $1\frac{1}{2}$ to 3 inches apart.

The literature on plant spacing indicates that spacing is important and that conclusions arrived at from spacings widely different from those used by farmers do not necessarily apply to farm conditions. It is therefore imperative when using nursery spacings differing from average field spacings, to determine the effect of the differences. If the desired spacings give misleading results it is probable that their use is not good breeding practice.

A critical comparative study of nursery spacings designed to discover whether different spacings change the ranking in a variety or strain trial theoretically should include a fair number of varieties or strains. At the outset of the present study the advantages of having a number of varieties of one crop was balanced against the need for information on three crops in which case the number of varieties in each would be small. The choice for each crop of two highly contrasted varieties appears to be satisfactory since any marked effect could be expected to be revealed by the selected pair of varieties.

The appearance of significant yield differences favouring Reward over Marquis in 1936 and 1938 at the 6-inch spacing but not for the 18-inch spacing suggests that the latter, the EE test, may be unreliable as a test of performance under farm conditions. However, critical analysis of the data showed that the only significant interaction between wheat varieties and spacings occurred in 1938 with respect to the 6-inch and 18-inch spacings. In no year was there a significant difference between the results from the 12-inch spacing and those from the EE test. Perhaps the most legitimate criticism of the EE test for wheat is that it resulted in smaller yield differences than were obtained with 6-inch or 12-inch spacings. The results indicate the desirability of the EE test not only for preliminary yield tests the year following plant progeny tests, but also as a standard comparative test of wheat varieties.

If the years 1936 and 1939 had occurred consecutively, selection of hybrid lines of oats during those years from a EE test might have meant discrimination against Banner-like lines as compared with Gopher-like lines. However, the lack of significance of the difference between Banner and Gopher indicates that the Banner-like lines would not have been

discarded. But even if they had, it would not have been a great disadvantage since Gopher showed, by its performance in 1937 and 1938, more drought resistance than Banner and in every year superior ability to utilize more space. It seems fair to conclude that the EE test is about as satisfactory as tests with the 6-inch or 12-inch spacings for preliminary comparison of oat lines.

The barley data for different spacings are consistent excepting for the 1938 tests where the varietal results at the 12-inch spacing as well as at the 6-inch spacing differed from those of the EE test. This occurrence indicates the need for a careful interpretation of the results of an EE test used on barley strains. However, it is important to keep in mind that the new method only showed significant insensitivity in one year out of four and that this insensitivity would tend to result in the continuance of some mediocre lines rather than the erronious discarding of promising lines. It may be concluded therefore that the use of the EE test is a satisfactory preliminary test for barley varieties even though it tends to mask the reaction of a variety to unfavourable circumstances.

In all three crops the evidence shows a general similarity in the relative performance of the varieties at the different row spacings, but the significant variety-spacing interactions in wheat and barley in 1938 and the fact that the spread between the variety yields decreased as the row spacing increased indicate that identical results cannot be expected from the different row spacings. However there is only one case in the four years of tests where a variety might have been discarded on the basis of the 6-inch and 12-inch tests but retained on the basis of the EE test, and that was in barley in 1938.

In conclusion, this study has shown that the EE test has one weakness, which is that the 18-inch spacing tends to show smaller yield differences between contrasted varieties than tests with either 6-inch or 12-inch spacings. That is to say, two varieties which might be significantly different in a test with rows 6 inches apart might not show a significant difference in the EE test. Such a situation occurred in both wheat and barley in the third year of the study. However, where the EE test is used exclusively as a preliminary yield test followed the next year by a 6-inch or 12-inch test this disadvantage is of small importance. At the worst it might result in some doubtful lines being carried on to the succeeding year's tests instead of being discarded.

Against this one disadvantage the EE test has several outstanding advantages over tests with rows 6 inches or 12 inches apart. The principal advantage of the new method is the fact that it requires only a small amount of seed (only 95 to 110 grams of spring sown grain) for a five or six replicate test. Since this amount of seed is easily produced by the progeny of a single plant, *an accurate yield test can be made the next year after the progeny of a single plant is considered uniform.* As a rule satisfactorily replicated rod row yield tests involving five or six rows 6 inches apart or three rows 12 inches apart cannot be made until a year later. A second advantage is the efficient utilization of space. Since the paths between series of plots and the one foot portions left at the ends of rows to eliminate border effect

are common to all three tests they may be left out of consideration in a comparison of methods. The EE test utilizes 100% of the space whereas the 6-inch and 12-inch row tests utilize only $33\frac{1}{3}\%$ of the space. A third advantage is economy of space, the EE test requiring a total of only half the space needed for the 6-inch and 12-inch tests. A fourth advantage is a distinct saving in all operations connected with the preparation of the land and seeding.

SUMMARY

1. A study was made to determine the effect of substituting rod row plots consisting of single rows spaced 18 inches apart for the usual rod row plots with several rows spaced 6 or 12 inches apart.

2. Two highly contrasted varieties of each of wheat, oats and barley were sown at the three different row spacings in a three-way split plot latin square every year during the period 1936 to 1939.

3. No variety-spacing relationships of importance were observed with respect to earliness of maturity or bushel weight in any of the crops.

4. Slight variety-spacing interactions were found for height of plant. One was in oats in 1937 and the other in wheat in 1939. In neither case was the relationship significant.

5. The variance analysis for grain yield showed significant differences between row spacings in 1936, 1937 and 1938 but not in 1939 or the period 1936 to 1938 as a whole.

6. In wheat, with one exception, there was no significant yield interaction between varieties and row spacings. The one case was in 1938 when the varietal difference at the 6-inch spacing was barely significantly different from the difference at the 18-inch spacing.

7. In oats there was no variety-spacing interaction of significance for yield.

8. In barley there were no important variety-spacing interactions for yield excepting in 1938 when Hannchen significantly outyielded Regal at the 6-inch and 12-inch spacing but not at the 18-inch spacing.

9. In general the 18-inch spacing tended to reduce the size of yield differences occurring at the 6-inch and 12-inch spacings. This was especially noticeable in the year 1938.

10. The results indicate that the EE test (single row plots 18 inches apart), while not an exact substitute for the 6-inch and 12-inch spacing methods, is a satisfactory comparative rod row test of cereal lines, and, on account of its distinct advantages, constitutes a valuable aid to the breeder.

ACKNOWLEDGMENTS

The writer wishes to express appreciation for the valued assistance of Mr. J. Whitehouse and other members of the Field Husbandry Department of the University of Saskatchewan in the field work, the statistical calculations and graphs.

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METHODS AND RATIONS FOR FATTENING POULTRY[1]

V. THE COMPARATIVE EFFECT OF HULLED OATS AND YELLOW CORN, OF SKIM MILK AND WATER, AND OF VARYING TEMPERATURES

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In continuation of research previously reported (1, 2, 3, 4) two feed differences and one management factor were investigated during November, 1939, as here reported. Previous work has indicated the relative value of the common cereals for the production of gain and for increase in fat (1, 4). The reason for the superiority of ground yellow corn and for the relatively poor results from ground oats does not seem to be apparent, however, and it was therefore decided to contrast oats and corn when the hull had been removed from the former to determine whether the hull may have been largely responsible for the relative inefficiency of this grain. Since the hull normally makes up 20 to 30% of the oat grain and may exceed this upper limit with certain varieties or if the grain is not plump, it can be appreciated that since the hull is practically indigestible and quite unpalatable to poultry, the efficiency of this grain for fattening may be greatly reduced.

Maw and Maw (7) working with 10-week old Leghorn broilers found ground oats to be superior in actual gains after 14 days fattening to corn, wheat, barley, hulless barley, and hulless oats. This finding is in contrast to that of Harshaw (5) and also to that of Maw et al. (6) and Gutteridge (4) both of whom used mature roasters for their tests. In every instance excepting the one quoted, corn was markedly superior to oats.

Almost without exception it is recommended that fattening feed be mixed with milk in some form. This recommendation is based largely on experience which has undoubtedly indicated the improvement which may be obtained by the use of skim milk or buttermilk as a mixer. Macdonald and Kay (8) came to the conclusion that a ration composed of 95% ground oats and 5% skim milk powder mixed with water gave as satisfactory fattening results as one made up of Sussex ground oats alone mixed with skim milk or with equal parts of skim milk and water. Little controlled evidence is available, however, to indicate whether and to what extent skim milk is superior to water when each is used as the sole mixer to a cereal fattening mash.

A problem of management which has been given very little attention from an experimental standpoint is the temperature of the room in which birds are fattened. It is commonly thought that low temperatures, besides increasing the requirement of feed for fuel purposes to maintain body heat, make the birds sufficiently uncomfortable that they do not gain or fatten well. High temperatures, on the other hand, are thought to put the birds off their feed and so reduce gains and fattening. Since this problem would seem to be of importance in view of the various temperatures under which

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birds are fattened at different seasons of the year and under different conditions of housing, the matter became a subject for experiment as here reported.

MATERIALS AND METHODS

There were used in these tests 144 Barred Rock cockerels of roaster age, all of which were fattened in individual cage batteries for a period of 2 weeks with 2 feedings daily. All birds were randomized according to hatch, battery, tier in the battery, feed and treatment. The following represents the allotment of treatments accorded:—

Group A—Fattened at an average temperature of 36.4° F.—range 23 to 48° F.

Group B—Fattened at an average temperature of 53.1° F.—range 46 to 62° F.

Group C—Fattened at an average temperature of 59.5° F.—range 49 to 70° F.

These temperatures were attained for group A by using a shed with open double doors thus giving little protection from outside temperatures, which in this latitude during early November, are relatively low. By so doing, fattening conditions throughout the surrounding country were simulated, but with additional severity since these birds were not closely grouped as is usually the case but were individually caged and unable to crowd for warmth; they also were on wire floors which tend to accelerate the heat loss from the body. Since the water in the drinking cups was often frozen in the morning it will be appreciated that more severe conditions will rarely be met with in actual practice. For groups B and C a heated room divided by a temporary canvas partition was used. It was not found possible to hold down the temperautre of group B to approximately 50° F., as was desired, but the mean differences in temperature of 16.7° F. and 6.4° F. cover a very satisfactory total range.

One-half of the birds of each of these groups received ground yellow corn as their cereal ration while the remaining birds were given ground hulled oats. It should be noted particularly that a preliminary test having shown commercial finely ground oat groats to be pasty and unpalatable because of fineness of grinding, the hulled oats used in this test were quite coarsely ground and highly satisfactory from the standpoint of palatability.

One-half of these groups in turn had their mash mixed with skim milk and the remaining birds with water. All groups had water to drink.

The data were analyzed by the methods of variance and covariance for gain and increase in percentage fat, and observed and adjusted means were calculated as in previously reported experiments (2, 9). The birds were also given commercial grading to determine differences in actual market quality, both as to degree of fatness and colour of fat.

RESULTS

Table I following shows mean gain and mean increase in percentage fat for the feeds and treatments of the experiment. Examination of these data indicates some striking differences. Ground hulled oats were significantly superior to ground yellow corn for gain, the latter giving only

TABLE 1.

Fattening treatment	Gain in body weight		Increase in fat	
	*Observed	Adjusted	*Observed	Adjusted
	gm.	gm.	%	%
Mean Temp. of 36.4° F.	327.83	286.33	25.03	25.00
Mean Temp. of 53.1° F.	292.06	312.84	23.32	21 97
Mean Temp. of 59.5° F.	288.56	309.28	24.20	25.58
Ground hulled oats	329.97	367.25	24.05	23.79
Ground yellow corn	275.67	238.39	24.31	24.57
Skim milk mixed	412.13	370.49	25.46	24.35
Water mixed	193.51	235.15	22.91	24.02

* Necessary difference at 19 : 1—for gain—temperatures 47.6 (48 birds), grains and mixers 38.9 (72 birds); for increase in percentage fat—temperatures 3.49; grains and mixers 2.85. (Observed means only.)

83.5% of the gain of the former. On the basis of equal feed consumption, starting weight, initial percentage fat and increase in percentage fat, the gains (adjusted) were also superior for hulled oats, the corn giving only 64.9% of the gains made by the first mentioned group. Similarly, skim milk was superior to water as a mixer, the comparable figures being 47.0% and 63.5% respectively. In regard to temperatures for fattening, although the largest gains were made at the lowest temperatures none of the observed differences are significant. Since the two high temperatures were significantly more efficient (adjusted gains), however, it becomes apparent that the gains at the low temperature were made at a cost of much greater feed consumption.

In view of the definite differences in gain between different treatments it is somewhat surprising to note that no significant differences in fat increase were recorded. It should be noted, however, that the increase in fat with skim milk as a mixer is on the border-line of significance and may represent a real effect.

The grading of the dressed carcasses indicated the following results:—

GRADING OF DRESSED CARCASSES

Fattening Treatment	Grade A	Grade B	Milk fed class
	%	%	%
Mean Temp. of 36.4° F.	83.33	16.67	31.25
Mean Temp. of 53.1° F.	82.98	17.02	27.66
Mean Temp. of 59.5° F.	85.42	14.58	25.00
Ground hulled oats	80.56	19.44	48 61
Ground yellow corn	87.32	12.68	7.04
Skim milk mixed	92.96	7.04	32.39
Water mixed	75.00	25.00	23.61

The above is on the basis of commercial grading, but neglecting pin feathers, skin tears, poor bleeding, etc. as causes for degrading. "Milk

fed class", as one class of the Canadian Government standards, implies whiteness of flesh rather than actual milk feeding which is not necessary to produce birds of this class under the regulations.

Differences between the various temperature groups are negligible. There is, however, a suggestion that a better grading for conformation and fat was brought about by the yellow corn, while there were 7 times as many white fleshed birds with oat feeding. Skim milk also produced a definitely greater percentage of A grade birds than did water as well as one-third more birds of the milk fed class.

DISCUSSION

Maw et al. (6), Gutteridge (4), and Harshaw (5) have published the results of research indicating yellow corn to be superior to oats for production of gain and fat. The two first mentioned authors carried out their tests on mature roasters whereas Maw (7) also used stock of broiler age and Harshaw (5) birds of this age only. With the exception of the one test on broilers by Maw et al. (6) there is unanimity of opinion as to the efficiency of corn over wheat, oats and barley, placing wheat a moderately close second and oats and barley somewhat inferior to these grains. The data here presented leave little doubt as to the greater efficiency of *hulled* oats over yellow corn for the production of gain, the difference being roughly 16%. The data also indicate a greater efficiency of production of gain for ground hulled oats. However, no more fat was laid down by hulled oats than corn, confirming previous findings that the latter grain is very efficient in fat production. It must be presumed, therefore, that the additional gain with hulled oats was in tissues other than fat. This is given further weight by the superior grading of the corn fattened birds. In view of the consistent superiority of corn to oats in the literature as above mentioned and since these findings were obtained from a very large population of birds (72 on each treatment), it may be presumed that hulled oats are distinctly superior to the whole grain, ground. This superiority without doubt must be attributed to the removal of the hull which as previously stated is both unpalatable and practically indigestible to poultry and may make up from 20 to 30% or more by weight of the total grain. These findings are in keeping with expectation based on the chemical analysis of the two grains concerned; hulled oats show 8 to 9% less moisture, 4 to 5% more protein, and 3 to 4% more fat on the average than corn. While this test affords no direct evidence, in view of the relatively poor and closely identical results of the whole grain, ground for both oats and barley, it is entirely possible that hulled barley would show a similar improvement over the unhulled grain in fattening efficiency.

Another and very striking result of this test is the superiority of skim milk as a mixer over water as evidenced by a 53% superiority in gain and a 36.5% superiority in efficiency of gain. The increase in percentage fat was also more efficient with skim milk, the difference being on the border-line of significance, however. The fact that a markedly superior grading of the dressed carcasses was evidenced for the milk mixed feed would lend weight to this difference and seem to suggest that this treatment was also actually superior in production of fat. Since there was a highly significant greater feed consumption of the milk mixed mash, palatability

may be considered to be a potent factor in the bringing about of this result. The fact that skim milk also supplies a moderate percentage of highly available nutrients should not, however, be overlooked. These results suggest that skim milk is an excellent mixer for fattening mashes and that this or a similar milk product should always be used in fattening, if available.

Considering the effect of temperature it is apparent from the data that satisfactory results may be obtained over a fairly wide range of mean temperatures, viz., 36.4° F. to 59.5° F. The extreme range in these tests was from 23° F. to 70° F. which should cover almost all possibilities under practical conditions of fattening. While the differences at the various temperatures were not significant the greatest difference was in favour of the lowest temperature and being close to significance suggests that the low temperatures at least could not have been detrimental. Fattening under farm conditions, therefore, should not be handicapped by temperature since there is little reason for temperatures at the fattening crate being any lower even under late season fattening conditions than were experienced in these wire floored batteries at 23° F. In addition, under ordinary conditions, the birds are confined in groups and can crowd for warmth. The consumption of feed was 8% greater at 36.4° F., indicating a greater requirement for maintenance of body temperature under cold conditions.

Some interesting facts are brought out by the commercial grading of the birds. No differences in grading were observed under the different temperature conditions. As previously noted ground yellow corn and skim milk showed a superiority to ground hulled oats and water respectively. Under Canadian Government Grading standards, in addition to a premium for grade A over grade B birds, a further and similar premium is paid for white fleshed or so called milk fed class birds over yellow fleshed birds. As would be expected ground oat groats were superior to yellow corn in this respect even with a short 2 weeks fattening period, and produced 7 times as many birds in the milk fed class as did yellow corn. In this connection it should be noted that ground white corn has been proven, by unpublished data at this Division, to be similar to yellow corn in production of gain and fat and to oats for the production of white fleshing. It is worthy of note that skim milk also had a whitening effect as evidenced by the production of one-third more white fleshed birds than was produced with water. It would seem that the premium for milk fed class birds can easily be assured by the use of a white grain with skim milk as a mixer.

SUMMARY

1. Ground hulled oats when coarsely ground were definitely superior to ground yellow corn for the production of gain in fattening. Since the latter grain has been shown to be consistently superior to ground oats it seems to be quite apparent that the removal of the hull from the oat grain is largely responsible for the superiority of hulled oats. In spite of this superiority for gain, ground yellow corn was equally efficient for the production of fat as indicated both by increase in percentage fat and by grading of the dressed carcasses. This confirms previous work indicating corn to be singularly efficient among the cereal grains in the production of fat.

2. Skim milk used as a mixer for a fattening mash gave very greatly superior gains to water for that purpose. It was also somewhat more efficient in the production of fat as indicated by increase in percentage fat and by grading.

3. The temperature condition under which the birds were fattened had no marked effect upon the gains made, and the lowest mean temperature, 36.4° F., showed a tendency to superiority in this respect. A greater feed consumption for maintenance of body temperature was evident at the lower temperature. Under practical conditions the temperature of the fattening room is probably of only limited significance since the extreme range in this test was 23 to 70° F.

4. The feeding of a white grain such as ground hulled oats had a very great effect on the production of white fleshed birds, while the use of skim milk as a mixer for the fattening mash produced a further whitening effect.

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PROTEIN-MINERAL-VITAMIN SUPPLEMENTS TO BARLEY IN MARKET HOG RATIONS[1]

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Recent experiments (1) have shown conclusively that high grade barley not only may constitute the entire basal feed for market hogs, but is probably superior as the basis of the bacon pig ration to either corn or oats. Barley, like other cereal grains, is deficient in several respects as a complete diet for pigs and requires supplementing with protein, minerals, and vitamins. Of these three groups of nutrients, the minerals offer the least difficulty in practical rationing because they are, in the quantities needed, a relatively inexpensive and easily procured part of the total feed. Furthermore, the exact amounts of calcium, phosphorus, iron, iodine and salt (NaCl) contained in minerals used in rations may be determined and their relative usefulness as mineral supplements predicted with reasonable accuracy.

Protein and vitamin supplements on the other hand present problems which cannot at present be solved by chemical means. Errors in meeting the pig's requirements for these nutrients are none the less serious. The economy of the ration is closely linked to the quantities of high protein feeds which must be used, and most vitamin concentrates are also expensive. Sub-optimum levels of intake on the other hand lead to slow growth, which in turn has been reported (4) to affect adversely the carcass excellence; to say nothing of all the unsatisfactory conditions which accompany a loss of thrift and vigour in the market pig.

Feeding standards at present in use have not been found wholly satisfactory in respect to protein levels, in part because of their failure to take into account the complicating factor of varying total food intake. Furthermore, biological values of protein are not in any case taken into account in feeding standards.

In this connection, tankage has frequently been considered the standard protein supplement for pig rations where milk was not available. Fish meal, however, has usually been found superior to tankage though often more expensive per ton. The possibility that the use of fish meal as a partial replacement for tankage might be advantageous can be answered by feeding tests only.

The vitamin requirements of pigs are not accurately known. Cod liver oil fed in usually recommended amounts probably meets minimum requirements for vitamins A and D. Experimental evidence now indicates that so-called standard pig rations appear frequently to be improved by the inclusion of special sources of the vitamin "B complex". Studies at the California Experiment Station (3) specifically showed barley to be deficient in some parts of vitamin B.

The answers to certain of these questions were sought in a feeding trial instituted at Macdonald College in the summer of 1939.

[1] Contribution from the Department of Animal Husbandry, Macdonald College (McGill University), Quebec.
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DESIGN OF THE EXPERIMENT

In the design of an experiment adequate to study the above problems, other factors known or suspected to affect the results must of course be controlled as far as possible. Thus seasonal differences in the growth of pigs, as between spring vs. fall born litters, needed to be taken into account, and also the question of sex.

In this trial, 96 purebred Yorkshire pigs were used, 48 from January born and 48 from May born litters. The pigs were sired by the same boar and were from dams that were themselves related as full or half sisters, or mothers and daughters. Individual penning and feeding was followed, the pigs being allotted at random to their pens, which at the same time determined the feeding group to which they were assigned. Males and females were randomized separately to put an equal number of each sex on each treatment. The pigs in any litter were started on trial when an age of 60 to 65 days of age was reached and were fed to a weight of approximately 200 pounds. All animals were confined to their pens throughout the trial. Until the pigs reached a weight of 110 pounds, feeding was done three times daily, and twice daily thereafter. For the entire period feed was given to the limit of appetite. At feeding times the dry meal allowance was placed in each trough and sufficient water poured over it to make a slop of 3 parts water to 1 part meal.

The rations used consisted of barley[1] to which was added (1) a mineral supplement and (2) a protein-vitamin supplement. For all lots the mineral supplement was made up of 2 parts bone char, 1 part ground limestone, and 1 part fine salt. It was added to the ration to constitute 2% of the final air dry mixture.

The rations differed in the composition of the protein-vitamin supplements and in the proportions in which these were added to the barley fraction of the mixture. The percentage make up of the protein-vitamin supplements used is shown in Table 1.

Table 1.—Protein-vitamin supplement

——	A	B	C	D	E	F
	%	%	%	%	%	%
Tankage	50	50	45	25	25	25
Fish meal	—	—	—	15	15	10
Linseed oilmeal	50	40	45	60	50	55
Milk powder	—	10	—	—	10	—
Brewers dried yeast*	—	—	10	—	—	10

* The brewers dried yeast was supplied gratis by National Breweries, Montreal, and their co-operation in this trial is gratefully acknowledged.

The proportions of basal feed, and protein-vitamin supplements used in each feeding group are indicated in Table 2. The letters in this table show which protein supplement was used, and the numerals are the numbers of the pigs allotted to the particular treatment indicated.

[1] Barley conforming in quality to 1938 specifications of No. 4 Canadian Western Feed Barley (2), viz., weight per bushel not less than 46 lb., with maximum tolerance of 3% weed seeds, 10% wild oats and other grains, and with total non-barley not exceeding 10%.

TABLE 2.—EXPERIMENTAL DESIGN OF THE FEEDING TEST

			Low protein level: Protein supplement constituting—15% from weaning to 70 lb., 15% from 70 lb. to 110 lb., 10% from 110 lb. to market				High protein level: Protein supplement constituting—25% from weaning to 70 lb., 15% from 70 lb. to 110 lb., 10% from 110 lb. to market			
			Supplements without fish meal		Supplements with fish meal		Supplements without fish meal		Supplements with fish meal	
January born pigs	Supplements without yeast or milk	♀	580 546	A	592 586	D	590 596	A	527 568	D
		♂	591 540	A	589 553	D	560 542	A	536 572	D
	Supplements with 10% milk	♀	539 531	B	547 599	E	597 548	B	528 598	E
		♂	550 519	B	556 529	E	534 538	B	573 585	E
	Supplements with 10% yeast	♀	525 549	C	551 594	F	577 567	C	595 517	F
		♂	533 566	C	574 570	F	552 571	C	587 535	F
May born pigs	Supplements without yeast or milk	♀	669 640	A	602 612	D	606 633	A	694 660	D
		♂	620 654	A	603 623	D	689 629	A	695 626	D
	Supplements with 10% milk	♀	644 625	B	619 642	E	632 609	B	656 643	E
		♂	657 637	B	606 693	E	628 601	B	616 668	E
	Supplements with 10% yeast	♀	655 630	C	692 600	F	607 634	C	635 671	F
		♂	614 615	C	679 604	F	605 631	C	622 651	F

The plan of the experiment was such that an analysis of the variance of the items of data recorded might be made as shown in Table 3.

RESULTS

The results of this work will for the sake of clarity be presented and discussed in two sections: the feed-trial data, and the carcass data.

FEEDING TRIAL RESULTS.

The feeding period in this test was divided into three parts, the first period ending for each pig when he reached a weight of 70 pounds, the second at 110 pounds, and the final at a market weight of approximately 200 pounds. This division of the feeding period was made in order to study the effects of boosting the protein level of the ration fed for the first few weeks following weaning. The mixtures used and the difference in protein levels are shown in Table 4.

TABLE 3.—ARRANGEMENT OF ANALYSIS OF VARIANCE

Variance due to	Degrees of freedom
All causes	95
Between 48 sub groups of two pigs each, made up of the variance:	47
Between two levels of protein (48 pigs each)	1
Between two groups (48 pigs each) testing fish meal vs. no fish meal	1
Between three groups (32 pigs each) testing milk vs. yeast	2
Between two sexes (48 pigs each)	1
Between two seasons (48 pigs each)	1
Interaction between groups	41
Within groups, i.e., residual or error variance	48

TABLE 4.—MEAL MIXTURES FED AND PERCENTAGE PROTEIN IN THEM*

Ration composition	Low protein			High protein		
	1st period	2nd period	3rd period	1st period	2nd period	3rd period
	%	%	%	%	%	%
Barley	83	83	88	73	83	88
Minerals	2	2	2	2	2	2
Protein supplement	15	15	10	25	15	10
Average percentage crude protein in rations	17.1	17.1	14.9	20.1	17.1	14.9

* For composition of protein supplement see Table 1.

Aside from observations of health, thrift and bloom of the pigs, the criteria of the relative values of the rations are largely rate of gain, feed consumption, and gain per unit of feed eaten.

Period I

These items for Period I are summarized in Table 5 the data of which reveal that:

(1) The extra protein fed resulted in a little faster gains by the young pigs.
(2) The inclusion of fish meal improves a protein supplement of tankage and linseed oilmeal.
(3) Additions of milk powder or yeast to the extent of 1.5% of the ration resulted in greater feed consumption and hence greater gains than were obtained in the check group.
(4) May born pigs made faster early gains than mid-winter born litters.
(5) Male pigs grew faster than females in the early part of the feeding period.

It may also be noted that pigs receiving the yeast or the milk powder showed during this period a greater bloom than did the check lot pigs. The difference in the hair coat and skin was quite apparent even to the casual observer.

TABLE 5.—GAINS AND FEED CONSUMPTION OF PIGS TO 70 POUNDS WEIGHT

Treatment	Number of pigs	Average daily gain	Average daily feed	Gain adjusted to average initial weight and feed intake
		lb.	lb.	lb.
High protein	48	.99*	2.83	1.00*
Low protein	48	.94	2.93	.92
Fish meal	48	.99*	2.86	.99*
No fish meal	48	.94	2.90	.93
Milk powder	32	.97*	2.94	.95
Yeast	32	1.00*	2.89	.99*
Nil	32	.91	2.80	.94
January born pigs	48	.93	2.88	.92
May born pigs	48	.99*	2.88	1.00*
Females	48	.93	2.84	.94
Males	48	.99*	2.91	.98*
General averages (n = 96)		.96	2.88	.96
Standard deviations (within groups)		± .12 lb.	± .25 lb.	± .09 lb.
Necessary difference (P = 0.05)				
For group of 48		.05	.10	.04
For group of 32		.06	.12	.05

* Significantly greater than comparative group.

Period II. Results at 110 Pounds Live Weight

The rather noticeable differences found in the growth of the different groups of pigs during the initial stages of the trial began to disappear as the feeding period progressed. By the time the pigs had reached 110 pounds the only significant differences to be found in gains (i.e., from the start of the trial) was between the summer and winter born pigs, and between the sexes. The May born pigs were gaining one-tenth of a pound more per day than the January born group, while the males were ahead of the females by a similar amount. Differences in feed intake were now insignificant excepting in the case of the May born pigs which were eating slightly greater quantities.

It was also noteworthy that there were now no obvious differences in health, thrift or bloom between any of the groups. All pigs were doing well, the average gain of the 96 since the start of the test being 1.19 pounds per day with an average daily feed intake of 3.74 pounds.

Period III. Results at Market Weight (200 lb.)

The mean gain in live weight during the finishing period was 1.74 pounds per pig per day made on an average daily intake of 6.98 pounds air dry feed. No marked differences were found between any of the ration groups, but the male pigs continued to lead the females in live weight gains (by 0.13 pounds per day) during this period. All pigs were marketed as they reached a weight of approximately 200 pounds. The exact shipping

weight was determined according to the conformation of the pig and his judged degree of fatness. The average shipping weight was 197 pounds with a standard deviation of ±8 pounds.

Total Feeding Period

A summary of the essential data for the entire feeding period is given in Table 6.

The results of the feeding tests are quite clear cut in so far as any of the rations fed are concerned. Differences in rate of gain traceable to ration composition are in no case large enough to result in more than about one week difference in total feeding period. When gains per unit of feed eaten are compared, there are no statistically significant differences between any of the groups excepting the two sexes. Here the males have continued to hold a small lead in gains.

When these results are compared with those for Period I it seems evident that the apparent benefits at the early part of the feeding of the higher protein of the fish meal additions, and the milk or yeast supplements are largely lost by the time a weight of 200 pounds is reached. This may not mean, however, that the greater thrift and bloom on the young pigs may not be a desirable condition.

The difference between the sexes is a factor of which more will be said later in this report.

TABLE 6.—SUMMARY OF GAINS AND FEED CONSUMPTION OF PIGS—TOTAL FEEDING PERIOD

Treatment	Number of pigs	Average daily gain	Average daily feed	Gain adjusted to average initial weight and feed intake
		lb.	lb.	lb.
High protein	48	1.42	5.12	1.42
Low protein	48	1.42	5.11	1.42
Fish meal	48	1.42	5.09	1.43
No fish meal	48	1.42	5.14	1.41
Milk powder	32	1.42	5.14	1.42
Yeast	32	1.45	5.17	1.44
Nil	32	1.38	5.04	1.40
January born pigs	48	1.39	4.90	1.44
May born pigs	48	1.45	5.34	1.40
Females	48	1.37	5.06	1.38
Males	48	1.47	5.17	1.46*
General averages	96	1.42	5.12	1.42
Standard deviation (within groups)		± .12	± .30	± .11
Necessary difference P = 0.05				
Groups of 48				.05
Groups of 32				.05

* Significantly greater than comparative group.

Carcass Studies

All pigs in this project were marketed through Canada Packers Limited.[1] Each pig was inspected by Dominion Government officials who graded the live hog and subsequently its carcass. Arrangements were also made to have one side of each carcass cut and measured according to the scheme used in the carcass tests of Swine Advanced Registry Policy. The scoring system was also that of the Advanced Registry Tests.[2] In connection with the item "firmness of fat" the descriptive grades were given numerical values as follows: (1) very firm, (2) fairly firm, (3) firm, (4) slightly soft, (5) soft, (6) very soft. This made it possible to subject this measurement of quality to statistical study. The data for each item recorded in the slaughter record were subjected to the same statistical analysis as used for the feeding trial figures.

A summary of the carcass data is given in Table 7.

The figures of Table 7 bring to light a number of things regarding the effect of ration on hog carcass. First may be noted the high carcass score of all pigs which, since all pigs were full fed, is evidence that heavy feeding does not damage carcass quality. (Under the Advanced Registry Scheme a minimum carcass score of 75 is demanded.)

Raising the protein level of the ration fed during the early stages of growth has been entirely without effect on the carcasses produced. Nor have the inclusion of fish meal, milk powder, or yeast made any differences in this respect. Indeed, a correlation of $r = -0.01$ between carcass score and rate of gain of the pigs to 70 pounds weight was found in these data. Hence the higher protein level, and the fish meal and the yeast, all of which resulted in faster early gains, did not in the end affect the carcass score.

Between January born and May born pigs, and between males and females, there are significant differences in carcass characteristics. Of necessity, the season of birth involves "sow differences" as well as any possible influence which the season itself might have on the pigs. The latter seems a remote possibility in this test since all pigs were fed in individual pens indoors throughout the tests. Nevertheless, there was a tendency for the January born pigs to produce carcasses with thicker neck fat and a less uniform back fat than the May born pigs. Furthermore, there was a suggestion that these fatter pigs had a somewhat smaller "eye of lean" in the bacon rasher. A significant correlation of $r = -0.41$ was found between eye of lean and depth of shoulder fat.

Sex differences are of course fundamentally hereditary. And between these two groups there are marked and practical differences in carcasses. At the outset, it will be noted that the carcasses of the male pigs were of considerably higher excellence as measured by carcass score. This is evidently not in any large degree traceable to length of carcass or to balance of side (percentage ham or percentage shoulder). Fat firmness is not directly a part of carcass score so that the slightly firmer "male" carcasses

[1] We are indebted to Canada Packers Limited for their co-operation in this test. They not only offered facilities and labour for special handling of the pigs and carcasses, but also absorbed the losses incidental to cutting the carcasses.

[2] Details of this scheme may be had direct from the Marketing Service, Dominion Department of Agriculture, Ottawa, Ontario. See reference (1) for scoring chart.

TABLE 7.—SUMMARY OF CARCASS DATA

Treatment	Carcass score	Cold carcass weight	Carcass length	Percentage ham	Percentage shoulder	Depth of neck fat	Difference in back fat	Fat firmness	Min. belly thickness	Grade of belly	Area loin muscle (Plan.)	Percentage lean in rasher
		lb.	in.	%	%	in.			in.			%
High protein	84.0	146.5	30.44	24.96	27.20	1.59	.66	1.90	.87	2.90	5.06	46.14
Low protein	85.0	145.9	30.50	24.82	27.42	1.65	.68	2.06	.84	2.94	5.17	46.09
Fish meal	85.0	146.0	30.48	24.83	27.27	1.65	.69	1.98	.86	2.98	5.15	45.86
No fish meal	84.0	146.4	30.46	24.94	27.35	1.59	.65	1.98	.86	2.85	5.07	46.37
Milk powder	85.5	146.8	30.49	24.84	27.16	1.65	.67	1.69	.90	3.03	4.97	46.85
Yeast	85.6	146.2	30.59	24.73	27.11	1.63	.68	2.12	.87	3.12	5.18	46.44
Nil	82.5	145.6	30.34	25.09	27.66	1.58	.65	2.12	.81	2.59	5.18	46.85
January born pigs	84.3	143.6	30.53	24.51	27.20	1.70	.74	2.12	.86	2.87	4.96	46.27
May born pigs	84.7	148.8	30.41	25.27	27.42	1.54	.60	1.83	.86	2.96	5.27	45.96
Females	81.4	148.3	30.58	25.16	27.69	1.61	.71	2.33	.81	2.56	5.42	48.44
Males	87.6	144.2	30.37	24.62	26.94	1.62	.62	1.62	.90	3.27	4.80	43.79
General Average	84.5	146.2	30.47	24.89	27.31	1.62	.67	1.98	.86	2.92	5.11	46.12
Standard deviation	±8.2	±6.1	± .73	±1.01	±1.18	±1.18	± .19	±1.08	± .21	± .89	± .50	± 3.83
Necessary difference												
Groups of 48	3.3	2.4	.29	.41	.47	.07	.08	.43	.09	.36	.20	1.53
Groups of 32	4.0	2.9	.36	.50	.58	.09	.09	.53	.11	.44	.25	1.88

do not explain the difference in score. The tendency for carcasses from female pigs to be softer than those from males has been found in other studies at this station, in which barrow carcasses proved to be more mature than those of gilts when killed at 200 pounds live weight, and carried less moisture in the fat depots.

From the standpoint of score, the advantage which the males showed appears to be largely traceable to the difference in uniformity of back fat and particularly to the quality of the belly. This is shown by the figures of Table 8.

TABLE 8.—ANALYSIS OF CARCASS SCORES

	Length of side	Depth and uniformity of fat	Balance of side	Belly grades	Eye of lean	Total score
Perfect score	20	20	20	20	20	100
Males	17.1	18.3	15.5	17.7	19.0	87.6
Females	17.4	16.3	14.2	13.5	19.9	81.3
Difference in points	−0.3	+2.0	+1.3	+4.2	−0.9	+6.3

Mention should be made of "eye of lean". From Table 7 it is evident that female pigs have a tendency at 200 pounds to greater leanness than the barrows. By actual planimeter readings of the surface area of the "eye of lean" in the full bacon rasher cut between the third and fourth lumbar vertebrae, the females were larger by almost two-thirds (0.62) of a square inch. This is an increase of 13%. The percentage of lean in the bacon rasher was found to be 48.4% in the female carcasses as against 43.8% in the males. Thus by either of these criteria, the carcasses from females have been the leaner. This difference has made but little difference in score because practically all of the carcasses carried an "eye of lean" well above the minimum and hence received no penalty.

DISCUSSION

In the final analysis, there are two factors which determine the success of any pig feeding enterprise, viz., the cost of the pig at market weight and the market value of the carcass produced. The nutritional value of the ration is admittedly an important consideration, determining whether or not production costs will be above or below the average at the time. Thus rations deficient in amounts or in quality of protein result in less gain for the feed eaten. Other things being equal, the ration which will permit the most rapid pig gains will be the most desirable—for rapid gains are usually relatively economical gains.

On the other hand, if rations which promote rapid gains are found to produce an inferior carcass, the lowered sale price of the carcass may easily overshadow any advantage in lowered cost of production.

From the results of this study, it would appear that none of the variations in the protein supplement have influenced in any way carcass score for excellence. The choice of supplement combination may therefore be made on the basis of rate and economy of gain of the pigs, and the ration

efficiency, with due consideration for such factors of health, bloom and vigour which doubtless play an indirect part in the performance of the live pigs. The data indicate that the yeast-containing rations, especially for the first month of the feeding period when the pigs are at the critical stage is advantageous. This fact is suggestive that fortification of the typical young pig ration with the vitamin B complex may be necessary for best results. This is in agreement with reports from California (3) to the effect that hog rations consisting largely of barley may require supplementing with certain vitamin B fractions. The inclusion of fish meal is also probably worth while, especially since as fed in these tests its use did not increase feed costs.

This situation regarding yeast and fish meal may be clearly shown by arranging the groups in order of their adjusted daily gains (i.e., adjusted to equal feed intake) as in Table 9.

TABLE 9.—AVERAGE DAILY GAINS OF PIGS TO MARKET WEIGHT ACCORDING TO RATIONS FED

Average daily gains, adjusted to equal feed intake and initial weight	Ration combination (See Table 2 for details)
lb.	
1.479	High protein + fish meal + yeast
1.468	Low protein + no fish + yeast
1.431	Low protein + fish meal + yeast
1.421	High protein + fish meal + milk powder
1.416	High protein + no fish + milk powder
1.415	Low protein + fish meal + milk powder
1.413	Low protein + fish meal + nil
1.407	High protein + fish meal + nil
1.406	Low protein + no fish + milk
1.398	High protein + no fish + yeast
1.389	High protein + no fish + nil
1.384	Low protein + no fish + nil
Average 1.42	

When the treatments are considered individually, it is not possible to demonstrate any significant difference in gains from fish meal vs. no fish meal, or in favour of yeast or milk powder. This is because the rates of gain were closely alike in such groupings. By sorting out the gains made by the various ration combinations, however, trends in rate of gain can be seen which should not be overlooked in interpreting these data.

When presented in order of gains, it is interesting to note that the four bottom groups were "no fish meal" lots and that in one case only did a "no fish" group gain above average, and in that case yeast was fed. It will also be noted that the top three lots received the yeast supplement and the next three the milk which is also a source of some fractions of the vitamin B complex, though of somewhat lower potency.

There is evidently no need for using extra protein at the start of the feeding period over that fed throughout the growing period. The extra cost of a month of feeding on a high protein "starter" could better be put toward the cost of including yeast or milk powder in the growing ration.

CONCLUSIONS

1. When the protein supplement consists of linseed oilmeal + tankage with or without fish meal, yeast or milk powder, there is no evidence from this test that increasing the crude protein level of the diet to pigs under 70 pounds live weight above 17% is advantageous. The increase in rate of gain resulting during this period is not maintained, and at market weight no consistent advantage of the high protein fed groups could be demonstrated. Thus the necessity for a special high protein "pig starter" may well be questioned.

2. The inclusion of fish meal in the tankage-oilmeal supplement cannot be considered an absolute essential as measured by ultimate average rate of gain over the whole feeding period or by any effect on carcass excellence. On the other hand, when the 12 groups of pigs (6 groups each on fish meal and no fish meal) are ranked in order of gain per unit of feed eaten, it is noteworthy that the 4 bottom groups were "no fish meal" lots and in but one case did a "no fish meal" lot stand above average in rank, and in that case yeast was fed. Fish meal groups also gained somewhat more rapidly at the start of the test. It would seem, therefore, that unless costs are prohibitive, the inclusion of fish meal in the protein supplement should be recommended.

3. With rations consisting largely of barley, inclusion of either yeast or milk powder (or some other source of the vitamin B complex) is likely to prove advantageous especially during the first month of feeding. The first 6 lots in order of gain received either yeast or milk powder in this test, with yeast in the 3 top ranking groups. The minimum quantities of these supplements sufficient to show any effects are not indicated in these data. In these tests these feeds constituted about 1.5% of the air dry feed.

4. There is enough difference in growth response and in carcass characteristics between male and female pigs to demand consideration from feeders. Not only may sex differences be expected to affect the percentage of hogs eligible for cash bonuses on routine rail grading but may complicate the question of qualifying sows for Advanced Registry. Pronounced sex differences were found in this study in rate of gain, carcass score, uniformity of back fat, firmness of fat, grade of belly, and leanness both absolute and in percentage. These findings indicate the need for consideration of sex in all comparative feeding tests in which carcass excellence is involved.

5. The differences between January born and May born pigs may be in part traceable to heredity since the two groups of pigs were subjected to practically identical management but were of necessity from separate groups of sows.

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STUDIES IN MATURITY AND COLD STORAGE OF PEACHES[1]

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In 1932, at the request of the Dominion Fruit Branch and with its co-operation, a study of the control of wastage in long-distance shipments of peaches was undertaken by the laboratory at St. Catharines. At first, attention was devoted entirely to brown rot, but it soon became obvious that the scope of the project should be enlarged since maturity, stage of ripeness at harvest, and post-harvest conditions had important bearings on the problem of wastage. Accordingly, in 1933, the study of maturity in peaches and plums, already under way as an independent investigation of the Fruit Branch, was incorporated in the co-operative program. In 1936 the Fruit Branch installed at St. Catharines two cold storage chambers to facilitate the investigation. The phase concerning brown rot of peaches has already been reported (28). The present paper deals first with criteria for judging maturity and the stages of ripeness at which peaches should be picked to withstand various shipping conditions, and second with the effects on peach fruit of the temperatures most commonly encountered during transportation either by train or by boat.

Prior to 1927, recommendations for harvesting peaches were based primarily on changes in colour, and secondarily on firmness to the touch (11). It was generally agreed that the fruit should be picked while still firm and when the ground colour, as distinguished from the blush, was turning yellow. For example, Duruz (14) suggested a light yellow or creamy white ground for white-fleshed peaches and a yellow or golden yellow for yellow-fleshed ones. In his opinion, peaches should never be picked according to firmness as determined by the pressure of the thumb.

Since the development of the penetrometer or pressure-tester, recommendations have become more definite. The penetrometer is a device for measuring directly in pounds the pressure necessary to force a cylindrical metal plunger, commonly $\frac{3}{16}$, $\frac{5}{16}$, or $\frac{7}{16}$ inches in diameter, a specified distance into the flesh of the fruit. As the resistance of the fruit to pressure usually collapses suddenly and allows the plunger to enter as far as it can, diameter is of much greater significance than the depth of penetration. According to Blake and Davidson (8), the pressure readings on fruit of the same absolute firmness are in the proportion of 1 : 2 : 3.3 for the $\frac{3}{16}$, $\frac{5}{16}$, and $\frac{7}{16}$ inch plungers respectively.

Blake (7), finding considerable variation between readings at different points on a single fruit, recommended taking the pressure through the skin at the softest point: 3.5 to 5.5 lb. ($\frac{3}{16}$ inch) for immediate use and 8 to 9 lb. for long distance shipping. Later Blake and Davidson (8) defined stages of ripeness in terms of pressure tests ($\frac{3}{16}$ inch) through the skin as follows: (1) *soft ripe*, for direct sale to consumer from orchard, 3 lb. or less; (2) *firm ripe*, for immediate sale and for freezing, 4 to 5.5 lb.; (3) *hard ripe*,

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for local markets, 6 to 7 lb.; (4) *nearby shipping*, up to 500 miles, 7·5 to 8.5 lb.; (5) *long-distance shipping*, over 800 miles, 8.5 to 10 lb. Croce (12) adapted this schedule to Argentinian conditions, lowering the standard by 1 to $1\frac{1}{2}$ lb. in each category except the first.

Morris (22) concluded that since colour provides the most practical means for differentiating between stages of ripeness, and since colour at any given stage of maturity varies from orchard to orchard and from year to year, pressure tests should be used to determine suitable colour standards for each picking. However, his data indicated that pressures ($\frac{5}{16}$ inch) through the skin of 12 to 18 lb. were best for commercial purposes, although fruit with lower pressure tests actually gained the highest quality.

Allen (2), using a $\frac{5}{16}$ inch plunger on peeled flesh, reported a rapid softening after the colour change commences. He recommended average picking pressures of 8 to 9 lb. for highly coloured, firm-fleshed varieties, and 12 to 14 lb. for Elberta.

Coe (11) developed a chart of colours to be used under Utah conditions and a standard of pressures using a $\frac{5}{16}$ inch tester on the unpeeled cheek. The range of colours and pressures at harvest in peaches subsequently attaining satisfactory quality varied somewhat with tree vigour, shading and weather. Pressures of 14 to 18 lb. and ground colour between greenish yellow and sulphur yellow were recommended for Elberta and Early Elberta. J. H. Hale could be picked at a more advanced colour, sulphur yellow to amber yellow, and at a slightly lower pressure, 12 to 17 lb.

Haller and Harding (16) advocated the following tests, with $\frac{5}{16}$ inch plunger on unpared cheeks: for Elberta, 11 to 14·5 lb.; for J. H. Hale, 11 to 16 lb.; for Belle of Georgia, 12·5 to 13·8 lb.; and for Carman, 9 to 12 lb.

Most of the above-mentioned workers are agreed that, since varietal behaviour, the growth status of the tree, rate of softening after harvest, seasonal variations and other factors must be taken into account, pressure tests for maturity should be used neither arbitrarily nor indiscriminately and are best adapted to supplement colour standards.

Less pressure is required for penetration when the fruit is turgid than when it is slightly wilted (8). Softening is accompanied by an increase in soluble pectins and a decrease in protopectin (3, 24) and is also correlated with a decrease in cellulose content and thickness of cell walls (24).

Other possible guides, such as freedom of pit, blush, form of fruit, and ease of separation of fruit from stem have been considered (12, 22) but have proved less reliable criteria for maturity than firmness and colour.

Thompson and Whittier (27) demonstrated an increase in soluble solids in peach juice over the entire developmental period but Allen (2) found that while soluble solids tended to increase as the peaches colour and soften, these changes were not always consistent. A general increase in sucrose content with ripening has also been demonstrated (2, 11, 24) but sugar determinations are not considered to be practicable as indices of maturity.

The well-known phenomenon of increase in size of peaches during ripening has also been investigated. McMunn and Dorsey (21) reported gains of 20.7 to 24.4% in volume during 7 days at harvest time, and Coe (11)

that the volume increased 42.8% between the first and third picks of Elberta. According to Allen (2) average daily gains in volume range from 2 to 7 cubic centimeters over a period of 10 to 14 days before harvest. It is thus obvious that there is considerable advantage in grade to be derived from delaying harvest as late as possible.

Considerable work has been done in connection with the various phases of storage and post-harvest behaviour of peaches. The rate of softening is very high at room temperature but drops rapidly as the storage temperature is lowered (16, 17, 22), though there are some differences between the responses of different varieties in this regard (16). Morris (22) came to the conclusion that temperatures of 40° to 50° F. were better than 32° F. for storage of peaches, on the grounds that those ripened at the lower temperature were uniformly of low quality. His records however show that peaches, particularly lots picked at the higher maturity levels, ripened fairly well at room temperature after 10 to 19 days at 32° F. In a later report (23), he stated that Elberta peaches deteriorated in storage 2 weeks earlier than J. H. Hale and Lavell. Harding and Haller (16) did not agree with Morris on the relation of temperature to quality, because in their experiments, although peaches ripened best at temperatures between 60° and 80° F., they were reasonably satisfactory after 1 or 2 weeks at 32° F., but showed marked decrease in quality either at 50° F. or when ripened at 70° F. after 1 or 2 weeks at 36° or 40° F. According to their data the maximum storage life at 32° F. is 2 to 3 weeks for Carman, Belle and Elberta, and 3 to 4 weeks for J. H. Hale. Huelin, Tindale and Trout (19), on the other hand, reported that Australian peaches could be ripened at 65° F. after 6 weeks in ordinary air at 32° F. and after about 9 weeks if the atmosphere contained 8 to 10% carbon dioxide.

The storage life of fruit at various temperatures depends not only on the rate of softening but also on respiratory activity. Cappelletti's studies (10) indicated that the respiratory rate of peaches at 2° C. was one-fifth that at 20° C. and increased 8 to 10 times when the fruit was transferred from 2° C. to 25° C. During this period of high activity, intramolecular respiration may set in and promote pronounced changes in flavour. Matsumoto (20) also found an abnormally high increase in respiratory activity after removal from cold storage. Harding and Haller (16) state that, on the basis of respiratory activity, 1 day at 70° F. is equivalent to 2 days at 60°, 4 at 50°, 8 at 40°, and 16 at 30° to 32° F. Their finding that the nature of respiration may also change with temperature lends support to their earlier conclusion (15) that at low temperature storage life is limited by physiological changes which may not be related to respiratory activity since the storage life of peaches at low temperature is not as long as the low rates of respiration and softening would indicate. According to Cappelletti (10) the sugar and fat contents of peaches at 2° C. were different from those at 20° C.

Physiological breakdown is also a determining factor in the storage life of peaches. Several types or stages of breakdown have been described, including woolliness or mealiness, water-soaking or injection of the flesh near the pit, and discoloration of the flesh, usually from the pit outward (4, 5, 13, 18, 25, 26). Davies *et al.* (13) also mentioned a pink discoloration in Elberta flesh. Harding and Haller (16, 18) observed no breakdown at

temperatures above 60° F., loss of flavour and mealiness at 50° F., and much earlier development of internal breakdown and browning at either 36° or 40° F. than at 32° F. Similar results were obtained with South African peaches (13) in that Peregrine, Elberta and other varieties developed breakdown sooner at 34° and 37° F. than at 31° F., and when ripened at 45° F. were not as good as when ripened at 65° F. Davies and his co-workers (13) recommend holding peaches at room temperature for 1 or 2 days before storage at 32° F. to reduce woolliness, but Morris (23) contends that this practice shortens their storage life. Barter (6) examined South African peaches on the English market and found considerable differences in varietal susceptibility to woolliness.

MATURITY STANDARDS

As Blake and Davidson (8) point out, the use of the terms "mature" and "maturity" in the fruit trade implies that fruit is mature when it is capable of ripening reasonably well and of attaining at least fairly good quality for the variety, if kept at room temperature after picking. These terms are used in this sense throughout the present paper and obviously must not be confused with the terms "ripe" and "ripeness" which imply edibility. The fact that peaches and many other fruits can be picked when mature but far from ripe is of immense advantage to the shipping trade.

Materials and Methods

For about a month before normal picking time samples of Rochester and Elberta peaches, as uniform and as representative as possible, were collected at regular intervals; 6 or 10 fruits of each sample were submitted to tests for colour, firmness, and concentration of soluble solids, while the remainder were set aside at room temperature for further observation. It was thus possible to determine the indices of the critical stage of maturity after which samples could be picked with assurance that they would soften and become more or less edible instead of becoming withered and leathery.

At each pick, each of the selected specimens was put through the following procedure. The colour of the ground or unblushed portion of the skin was matched with Ridgeway's colour standards. Then the firmness of each unpeeled cheek was measured by means of a Ballauf penetrometer with a $\frac{5}{16}$ inch plunger, except in 1933 and the early readings of 1934 when only a $\frac{7}{16}$ inch one was available. Next the flesh colour was recorded from slices cut off at the stem end and at the blossom end of the pit. Finally the juice was expressed separately from each slice and the percentage of soluble solids therein read by means of a Bausch and Lomb refractometer. Both the hand press used for juice extraction and the refractometer were washed with distilled water and wiped dry with a clean cloth between readings.

Pressure Tests

Each year the first tests were either at or above the upper register of the penetrometer, that is, 30 lb. or more. From then until maturity a gradual softening could be traced. During this stage of development comparatively little variation was observed between readings on the same fruit or on different fruits of the same sample. In the five seasons that

the pre-harvest tests were followed, both Rochester and Elberta varieties became mature by the time their firmness registered an average of 19 to 20 lb. with a $\frac{5}{16}$ inch instrument, or the equivalent with $\frac{7}{16}$ inch, except in 1937 when pressures fell to a 17 lb. average before maturity in the case of Rochester. This discrepancy, probably due to a change in the manurial program, while not very great implies that the standard for estimating maturity should not be too rigid.

After maturity softening proceeded at a more rapid rate until, in ripe fruit, resistance to pressure was negligible. During this stage there was considerable variation in the pressure readings, illustrated in a different connection in Tables 5 and 7. This feature is interpreted as denoting a differential in rate of softening, both in different fruits and in different parts of the same fruit, set up by differences in location on the tree and in exposure to sunlight. However, as the carrying and keeping quality of peaches depend largely on firmness, the pressure test, in spite of variability, provides, if used with discretion, one of the most valuable indications of the picking stage suitable for any particular purpose.

In making determinations of firmness, it is important that pressure should be applied slowly and at a uniform rate on different specimens, if results are to be compared. For this reason, tests should be made by the same operator throughout the season. It is advisable to make tests on samples of 10 or more peaches and to average the results, as data from single tests are likely to be misleading.

Soluble Solids

The use of either the hydrometer or the refractometer for determining the stages of maturity of fruits is based on the hypothesis that sugars make

TABLE 1.—CORRELATION CHART OF PRESSURE TESTS THROUGH SKIN AND PERCENTAGES OF SOLUBLE SOLIDS IN PEACHES, VARIETY ELBERTA, 1933

		Pressure in pounds—through skin ($\frac{7}{16}$)"														Total
		3–4	5–6	7–8	9–10	11–12	13–14	15–16	17–18	19–20	21–22	23–24	25–26	27–28	29–30	
Refractometer readings (per cent soluble solids)	8.4 – 8.6												*2	1	2	5
	8.8 – 9.0											1	1	—	1	3
	9.2 – 9.4			1	4	—	—	2	1	2	2	2	—	—	2	16
	9.6 – 9.8	1	1	—	—	—	3	2	—	2	2	4	1	3	5	24
	10.0 – 10.2	—	—	2	—	—	—	1	1	—	2	—	1	—	2	9
	10.4 – 10.6	—	—	1	2	4	—	—	3	2	1	1	2	2	5	23
	10.8 – 11.0	1	1	2	3	—	1	1	—	—	—	1	—	1	4	15
	11.2 – 11.4		2	2	2	1	—	—	—	1	—	2	—	—	1	11
	11.6 – 11.8			1	—	—	—	—	1	—	—	—	1	1	1	5
	12.0 – 12.2			—	—	—	—	—	—	1	—	—	—	—	1	2
	12.4 – 12.6			1	1	—	—	2	—	1	—					5
	12.8 – 13.0					—										0
	13.2 – 13.4					1										1
Total		2	4	10	12	6	4	8	6	9	7	11	8	8	24	119

* The figures denote frequency of occurrence.

up the major proportion of solids dissolved in the juice and that they accumulate more or less uniformly during the ripening process. In the present investigation, while there was usually a tendency for the percentage of soluble solids in peach juice to increase during the critical period before and after maturity, the trends were neither definite nor consistent enough to be of value. There was evidence to show that fluctuations occurred in response to factors other than developmental changes, for example: position and extent of blush, heavy rains, dry periods, etc.

Table 1 illustrates the more or less random relationship usually obtaining between pressure tests and refractometer readings, while the coefficients of correlation between the two are given in Table 2. The data for the Rochester variety in 1934 were not correlated because the pressure tester was changed during the experiment. However, the coefficient would undoubtedly have been more highly negative than that for Elberta in 1934, because the soluble solid concentration for successive picks rose more regularly and more distinctly than in any other similar experiment. It should be noted that, instead of being negative the correlation for Rochester was positive in 1933 (Table 2) and that in general, besides being low, the correlations varied considerably. Therefore, as the firmness of the fruit has already been shown to be a reasonably good, practical index of maturity and picking stage of peaches, it may be concluded that the soluble solid content of the juice is not.

TABLE 2.—COEFFICIENTS OF CORRELATION BETWEEN PRESSURE TESTS THROUGH THE SKIN AND THE PERCENTAGE OF SOLUBLE SOLIDS IN THE EXPRESSED JUICE OF PEACHES OF THE ROCHESTER AND ELBERTA VARIETIES FOR THE YEARS 1933 AND 1934

Variety	1933	1934
Rochester	+0.1751	—
Elberta	−0.2521	−0.4852

Direct correlation failing, it was thought from early observations that maturity in peaches might be denoted by a maximum spread between refractometer readings at the stem end and at the blossom end. But here again consistent results could not be obtained with either variety in any one season or with one variety in different seasons. There was, however, a tendency to greater variation between the readings from opposite ends of the fruit during intermediate ripening stages. As its use was both unsatisfactory from any point of view and too complicated for field work the refractometer was abandoned in 1935 as far as peaches were concerned.

Colour Changes

Since the accurate judging of the colour of peaches presents practical difficulties arising from the large numbers and the intergradations of shades encountered in different fruits and even in a single fruit, as well as from the superimposing of blush on ground colour, the shades listed in Table 3

TABLE 3.—CORRELATION CHART OF PRESSURE TESTS THROUGH THE SKIN AND GROUND COLOUR IN PEACHES, VARIETY ROCHESTER, IN 1934 AND 1935 (BLACK)

Pressure (skin)	Lime & citron green	Clear dull green yellow	Chrysolite green	Chalcedony yellow	Reed and barium yellow	Citron yellow	Martius & baryta yellow	Amber & straw yellow	Pinard & Empire yellow	Buff yellow	Apricot yellow	Pale & light orange yellow	Totals 1934	Totals 1935
29			*1										1	
28			1										1	
27	*1		–		*								–	1
26	2		2 1										2	3
25	4		–										–	4
24	11		1			1							1	12
23	10		5	2		6		1					9	15
22	16	1	3	3 1	1 2	5		–					9	23
21	21		7	1	3 2	13		–					17	30
20	15		6	2	2 3	25		3	1				33	24
19	7		3	1	5 –	11 1		2	1	1			21	11
18	7		1	1	3 –	25 1	1	7	1	–			38	9
17	3		–	1	3 1	25	1	6	1	–			37	4
16	1		–	1	4	11	1	5	2	1			25	1
15	1		–		2	5		5	5	1	1	1	20	1
14	–		–		1	2		3	5	1	–	1	13	–
13	1		1			4		1	1	2	1	–	9	2
12						1		1	2	–	2	–	6	
11								2	2	–	–	–	4	
10								–	2	–	1	–	3	
9								–	1	–	–	1	2	
8								–	–	–	2	–	2	
7								1	2	2	1	1	7	
6									2	1	3	2	8	
5									5	3	2	1	11	
4									1	3	1	2	7	
3									2	1	1	2	6	
1935	100	1	28	1	8	2								140
1934			4	12	24	134	3	37	36	16	15	11	292	

* Figures denote frequency of occurrence.

are at best approximations. Colour records are also subject to the limitation that colour sense may vary markedly among different observers. Nevertheless, it is well known that trends in colour from green to yellow do accompany the ripening process and can be used with certain provisos as criteria of ripeness.

Table 3 is a pair of distribution charts showing the frequency with which each ground colour occurred in association with coincidental pressure tests and illustrates the fact that colour and pressure relations may vary considerably from year to year. The assignment of consecutive numerical values to the colours, begining with 1 at the yellow end of the range, made it possible to calculate the simple inter-class coefficient of correlation between the two characteristics of firmness and colour. The other correlation coefficients given in this paper were calculated in the same way.

There was in Elberta a fairly high degree of correlation between flesh colour and firmness in both 1934 and 1935 (Table 4). In Rochester, on the other hand, flesh colour was not correlated so highly with pressure.

TABLE 4.—COEFFICIENTS OF CORRELATION BETWEEN PRESSURE TESTS AND COLOUR IN ROCHESTER AND ELBERTA PEACHES FOR THE YEARS 1933–35

Correlation between	Rochester		Elberta		
	1934	1935	1933	1934	1935
Pressure through skin and ground colour	0.701	0.114	0.832	0.743	—
Pressure through skin and flesh colour	0.383	0.448	0.606	0.795	0.759

As mentioned above, both varieties were mature in these years when average pressure reached 19 to 20 lb., but where in 1934 the pressure ground-colour correlation was in the neighbourhood of 0·7 for each variety, in 1935 it was 0·1 for Rochester (Table 4), while in Elberta ground colour did not advance beyond chrysolite green in fruits registering pressure tests ranging from 18 to 30 lb. A similar condition (Table 3) explains the low correlation in 1935 for the Rochester variety. These varying colour-pressure relationships indicate that the processes governing changes in firmness and those governing changes of colour, while more or less parallel, are actually independent and may take place at the same rate and time in some fruits and in some seasons, but at a different rate and time in others. For example, in 1935, both varieties began to soften and to mature before they started to change colour, while in 1934 both changes began to occur at about the same time. In some years, therefore, it can be expected that peaches may be ready to pick before a marked colour change occurs. This happened again with Elberta in 1938 and to a lesser extent in 1936. Colour then can be considered less reliable than firmness as an indicator of maturity, keeping quality and picking stage.

It should be pointed out, however, that while colour may not be a reliable criterion of the various developmental stages throughout a whole season or from season to season, it has been found a valuable basis on which to grade the fruit of a single pick into different lots of reasonably uniform ripeness. Such lots, for example, were used in the storage trials discussed later in the present paper.

In considering the colour changes in relation to one another, in a single variety during the same season, it is of interest to note that, though ground and flesh passed through much the same range of colours, the latter was considerably in advance of the former until the fruit was almost ripe. In Rochester, ground colour eventually surpassed flesh colour in 1934, while in 1935 it was impossible to follow the process to the end because in the later stages ground colour was almost totally obscured by blush.

In the last analysis, from the practical point of view, ground colour has to be the basis for deciding which peaches should be harvested at any one time as well as for grading for packs of uniform ripeness, but no one colour can be selected as a standard applicable either from year to year or even from orchard to orchard, because in some years the peaches would

be too soft to ship well by the time they became that particular colour. The colour standard, therefore, should be determined for each pick, and it is here that the pressure test can be used to advantage. The pressure test also has an important place if decision has to be made either on the maturity status of a pack of peaches or on its suitability for such purposes as storage, shipments to local or to distant markets and so on.

STORAGE TRIALS

The effect of temperature on keeping quality and wastage has been investigated during four seasons, 1936 to 1939 inclusive, in the case of the early variety, Rochester, and of the late variety, Elberta. The mid-season varieties, Valiant and Vedette, have also been under observation since 1937. The storage temperatures, 45° F. and 33° F., were chosen for study because they represent respectively the temperatures prevailing in refrigerator cars used for transport to Western Canada and in the cold storage chambers of ships going to overseas markets.

Materials and Methods

Immediately after harvest each pick was carefully sorted into 3 classes according to ripeness on the basis of ground colour, after culling fruits with obvious bruises and other defects. Although, through difficulty in classifying some of the border-line specimens, the categories may have overlapped slightly, they were distinct enough to show considerable difference in behaviour later on. In some picks, each class was represented in sufficient quantity to permit a complete series, but the ripest grade usually did not provide a full complement. Wherever only 1 grade was carried through, as in the case of Vedette and Valiant throughout and in the other varieties in 1939, the intermediate class was selected for experiment.

After sorting, a sample of 10 fruits from each class was tested for firmness and other characteristics. Each group was subdivided into a number of lots, packed unwrapped in 2 layers in open wooden trays, each containing 60 to 70 peaches. One lot was kept for immediate ripening at room temperature and the remainder were at once put into cold store, some at 45° F. and some at 33° F. At intervals, 1 trayful from each group represented was withdrawn from each storage chamber to ripen at room temperature; some lots were maintained continuously in cold storage. Samples of the latter, usually 10 fruits each, were examined from time to time for firmness, feel, flavour, texture, colour, free juice and internal breakdown. Similar observations were made at short intervals during the ripening period in the case of the lots removed from store. Throughout the experiments, 4 pressure tests, 1 through the skin, and 1 on peeled flesh on each cheek, were taken on each individual fruit in a sample. Thus, for each sampling, there were available for statistical analysis 20 readings through the skin and 20 on peeled flesh.

Pressure Tests

It is obvious that any class, or lot, of peaches selected on a colour basis would show considerable variability in firmness, which would limit the degree of significance to be placed on pressure tests obtained from such fruit. It was considered necessary, therefore, to subject the data obtained from the pressure tests to a certain amount of statistical analysis. Accordingly, the standard deviation, the standard error of the mean and probable

error, were calculated for each sampling in one complete series and, in the rest, for samples departing perceptibly from the general trend. In Figures 1 and 2, the short vertical lines at various points along the curves mark the range which is obtained by adding the standard error to and subtracting it from the mean pressure of the sample concerned and within which the curve is considered to fall. The relatively high standard of error for some

TABLE 5.—CORRELATION CHART OF PAIRED PRESSURE TEST READINGS ON PEACH FRUITS, VARIETY ROCHESTER, 1939

Pressure in pounds—larger reading (skin)	Totals	(Pressure in pounds—larger reading (pared flesh)) 0	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19		Pressure in pounds—smaller reading (pared flesh)
	Totals	79	30	23	16	21	37	45	63	69	46	19	4	2	1					455	
		*79	22	12	5	6	7	6	4	5	1	1								148	0
			8	5	4	7	7	4	6	5	1	–								47	3
				6	3	1	2	6	4	4	1	–								27	4
					4	4	5	3	2	3	1	–								22	5
0	2	2				3	8	7	5	4	3	1								31	6
3	5	3	2				8	8	6	5	3	2								32	7
4	30	3	21	6				11	20	9	3	3								46	8
5	23	3	1	11	8				16	22	13	3								54	9
										12	9	2	–	1	1					25	10
6	23	2	1	7	11	2															
7	20		2	2	8	5	3				11	5	3	1	–					20	11
8	21		1	3	6	7	2	2				2	1	–	–					3	12
9	13		–	–	3	1	2	5	2												
10	18		1	1	3	1	3	2	2	5											
11	19		–	–	2	3	1	5	2	3	3										
12	26		–	–	4	1	3	1	5	3	2	7									
13	32		1	1	1	3	7	1	3	2	3	5	5								
14	40			3	2	1	1	–	4	3	3	5	10	8							
15	49			1	–	4	1	3	4	3	2	5	7	9	10						
16	43			1	–	–	1	2	–	3	2	5	1	8	13	7					
17	41				–		1	2	–	2	3	1	1	9	11	9	2				
18	32				1	–	1	1	1	–	–	2	2	5	5	7	5	2			
19	14									–				1	3	4	3	1	2		
20	3									-				1	1				1		
21	1									1				–	–				–		
	455	13	30	36	49	28	26	24	23	25	18	30	26	41	43	27	10	3	3	Totals	
		0	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19		

Pressure in pounds—smaller readings (skin)

* Figures denote frequency of occurrence; for tests on pared flesh (in black) in upper right; for tests through skin in lower left.

of the samples was evidently due either to sampling error or to variability inherent in individual fruits or both. The evidence based on pressure tests, therefore, should be regarded as valid only when it is applied to outlining the general direction of changes in firmness. For this reason the curves for each series were smoothed out in Figures 1 and 2 and the fluctuations from sample to sample, not being significant, were disregarded.

Table 5 illustrates the frequency with which various combinations of pressure tests on opposite sides of individual fruits were found. In the majority of cases the value on one cheek corresponded fairly closely to that on the other, as indicated by the coefficient of correlation (Table 6), but sometimes there was as much variation between values on opposite sides of the same fruit as there was between mean values for individuals

at opposite extremes in a sample. This inherent variability in firmness was somewhat greater in Rochester than in Elberta (Table 6) and in peaches of medium firmness than in either very soft or very firm ones. This factor, therefore, shares with errors due to sampling the responsibility for the fluctuations mentioned in the previous paragraph.

TABLE 6.—COEFFICIENTS OF CORRELATION BETWEEN PAIRS OF PRESSURE TESTS ON OPPOSITE SIDES OF INDIVIDUAL FRUITS AND BETWEEN SKIN AND FLESH TESTS ON THE SAME SIDE OF INDIVIDUAL PEACHES OF THE VARIETIES ROCHESTER AND ELBERTA FOR THE YEAR 1939

Correlation between	Rochester	Elberta
*Pairs of tests through skin	0·6989	0·8779
*Pairs of tests on peeled flesh	0·6859	·8653
Pressure through skin and pressure on peeled flesh	0·8920	·9335

* Coefficients calculated from symmetrical correlation tables.

TABLE 7.—CORRELATION CHART OF PRESSURE TESTS THROUGH SKIN AND ON PARED FLESH IN PEACHES, VARIETY ROCHESTER, 1939

Pressure in pounds (pared flesh)	Pressure in pounds—(through skin)																				Total
	0	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
0	*14	32	61	60	30	13	9	2	2	1	2	–	1								227
3	–	2	3	12	14	13	11	10	7	1	1	–	2	1							77
4	–	–	1	–	2	11	6	5	7	9	2	5	1	–	1						50
5	–	–	1	–	3	6	7	3	3	3	3	4	3	1	–	–	1				38
6	1	–	–	–	1	3	5	5	13	2	4	7	6	4	1	–	–				52
7		–	–	–	1	–	2	6	5	8	15	5	17	4	5	1	–				69
8		1	–	–	–	–	2	5	3	10	11	16	15	16	6	4	1	1			91
9							2	–	1	2	13	16	25	30	15	9	3	1			117
10							1	–	2	1	2	5	8	19	24	15	10	5	2		94
11											3	–	2	13	11	17	13	6	–	1	66
12													1	4	6	4	6	1	–		22
13															1	–	–	2	1		4
14																1	1	–			2
15																		1			1
Total	15	35	66	72	51	46	45	36	43	37	56	58	81	92	70	51	35	17	3	1	910

* Figures denote frequency of occurrence.

It should be noted, for either variety, that while the coefficients of correlation between skin and flesh tests on the same side of the fruit (Tables 6 and 7) are higher than those for the paired readings on opposite cheeks (Tables 5 and 6) there is little difference between the coefficient for paired readings through the skin and that for paired readings on peeled flesh. From the statistical point of view, therefore, there is little to choose between taking pressure readings through the skin and taking them on peeled flesh. From the practical point of view, however, the skin tests would be preferable for, besides being easier to take, they are on the average 5 to 6 pounds higher than those for peeled flesh and could thus be followed for a longer period if necessary. The pressure exerted by the skin itself is also a factor

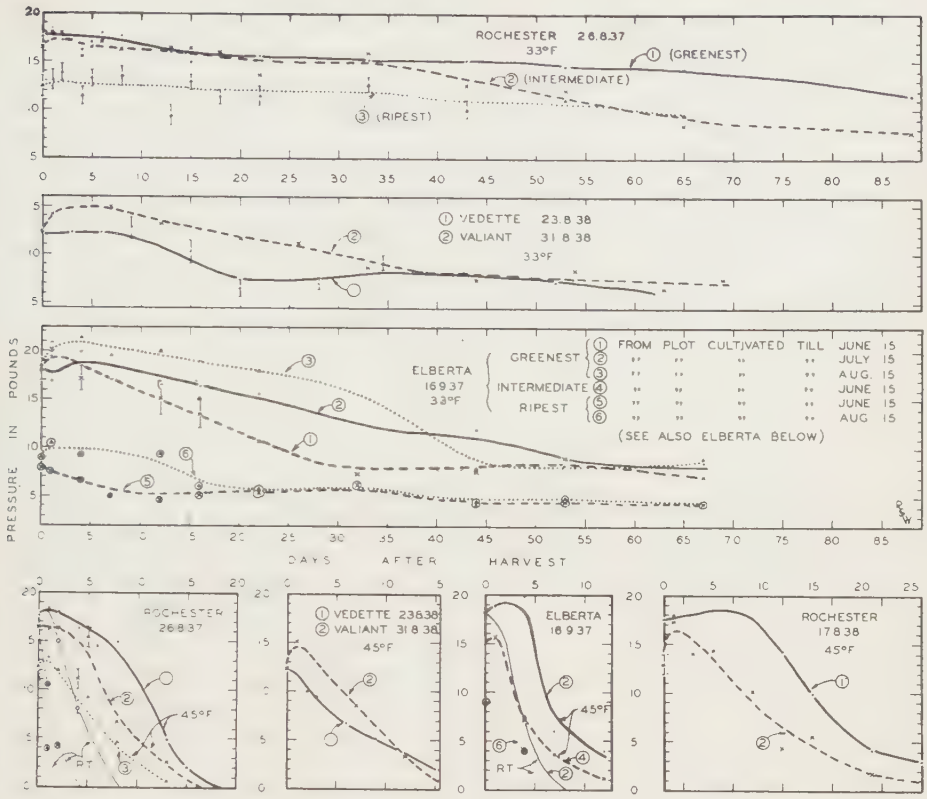

FIGURE 1. Changes in firmness in peaches at different stages of ripeness, at room temperature (R.T.), during storage at 45° F. and at 33° F. Rochester variety, picked Aug. 26, 1937, also Aug. 17, 1938 (at 45° F.); Vedette, Valiant and Elberta picked respectively Aug. 23, Aug. 31, and Sept. 16, 1937. Tests through skin (5/16″).

likely to affect the carrying capacity of a pack. Accordingly, only skin pressures are referred to hereafter.

Subject to the qualifications mentioned in the first paragraph of this section, the pressure changes through which the different varieties passed under various storage conditions in two different seasons, are presented in Figures 1 and 2. The observations for the 2 years not represented do not differ materially from those shown. All varieties softened rapidly at room temperature (Rochester and Elberta, Figure 1), particularly the riper grades which usually became eating ripe within 2 or 3 days of harvest. The greener grades, even when very little firmer at picking time, ripened more slowly.

Storage at 45° F. prolonged the softening process considerably, although the rate varied from season to season (cf. Rochester, 1937 and 1938, Figure 1) (also Elberta, 1937, Figure 1 and 1939, Figure 2). Although softening frequently commenced at once, sometimes it was delayed during the first few days in storage during which time the fruit occasionally even became firmer. In the latter instance, the subsequent drop in pressure was usually more rapid than when there was no initial delay. Regardless of its firmness at the beginning of the storage period, mature fruit of all

varieties reached a pressure of 4 pounds or less within 3 weeks. In each season, Elberta consistently softened more quickly than Rochester at 45° F.

The rate of softening was lowered still further by storage at 33° F. Indeed, the fruit remained firm until long after it had lost the ability to ripen when returned to room temperature. While Rochester peaches could be relied upon to show at most a very gradual decline in firmness, the pressure changes in Elberta could not be forecast with any degree of certainty, especially if the initial pressure registered between 12 and 18 lb. On the other hand, Elberta peaches softer than 10 lb. at picking, changed relatively little during the period of observation (see Figure 1, the ripest grade in 1937).

In connection with the seasonal differences in behaviour of peaches in storage, a very interesting similarity is to be noted between the 45° and 33° curves for a single variety in any one year. This suggests that the softening process at both temperatures is influenced in the same direction by the pre-harvest factors affecting a given pick in a given year. In most instances, the 45° curve for each variety, though more downward deflected, is in main outline a compressed version of the 33° curve for the same pick. That is to say, the sequence of pressure changes occurring at 45° F., while both more exaggerated and more rapid, was much the same as that occurring in comparable lots at 33° F. The most striking example of this similarity of configuration is afforded by the 2 picks of Valiant and of Vedette in 1938 and 1939 (Figures 1 and 2). The other varieties, however, showed

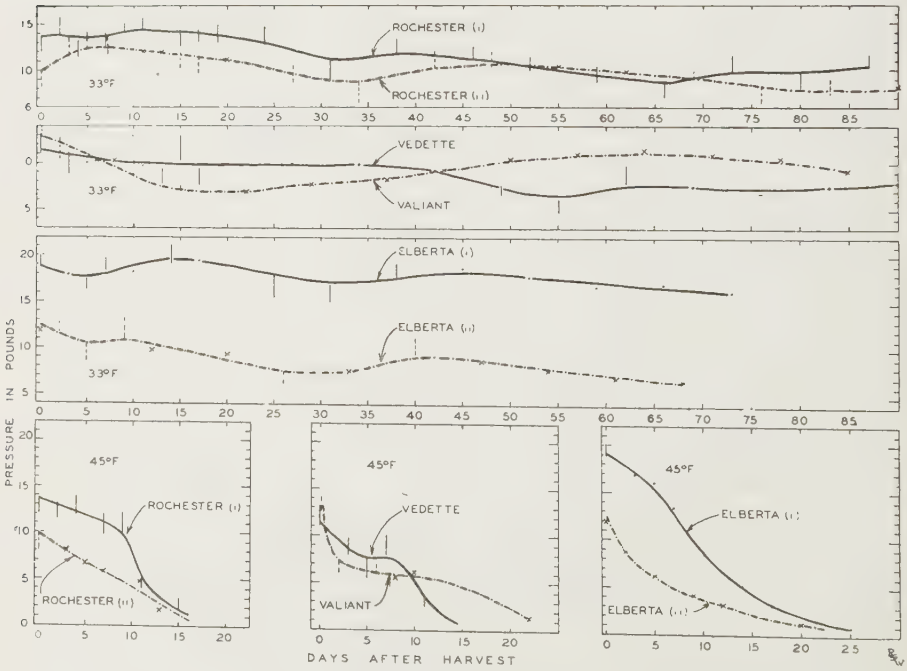

FIGURE 2. Changes in firmness in peaches of different picks, during storage at 45° F. and at 33° F. Rochester variety (i) picked Aug. 21, (ii) Aug. 25, 1939; Vedette, Aug. 25, 1939; Valiant, Aug. 30, 1939, and Elberta, (i) Sept. 11, (ii) Sept. 16, 1939.

in varying degrees the same sort of parallelism, for, considering comparable lots, Elberta softened more rapidly at both temperature in 1937 than in 1939, and Rochester in both 1937 and 1939 than in 1938. Valiant, on the other hand, softened more slowly in 1937 than in 1938. Incidentally, the 33° curve for Rochester in 1938 (not figured) bears some resemblance to the atypical Valiant curve for 1939 (Figure 2). The fact that the different varieties were not influenced in the same way in the same season suggested that conditions during the earlier part of the summer had less effect upon keeping quality than had conditions during the ripening period. A comparison of the weather records for the seasons concerned lead to the conclusion that, while air temperatures during 1 to 2 weeks before harvest appeared to have a predominating influence, their effects were complicated by those of hours of sunshine, relative humidity and precipitation. Although the available data were too limited for defining the full implications of the interaction of these factors, they were sufficient to indicate that peaches kept better when ripened steadily under favourable combinations of conditions, such as moderately high temperature, bright sunlight and variable but not extreme relative humidity, than when ripening was delayed by dull, cool, damp weather. That the lateness of its normal ripening is likely to expose Elberta, more than other varieties, to unfavourable ripening conditions may account, in part at least, for its poorer showing and greater variability in storage.

According to the 1937 data for Elberta (Figure 1), cultural practice also affected the rate of softening of peaches in storage. Fruit from the plot cultivated annually until August 15, remained firm for 4 weeks at 33° F., while that from the plot cultivated until June 15, softened steadily during the same period. This behaviour was like that described by Blake *et al.* (36) for fruit from "high nitrogen" and "high carbohydrate" trees, respectively. Indeed, the trees themselves in the two plots showed corresponding tendencies in their vegetative characters.

Quality

Peaches ripened at room temperature without cold storage developed good to very good flavour and colour for the variety, melting texture, and considerable to abundant free juice in all lots whose average initial skin pressure was 14 lb. or less. Peaches picked at 14 to 18 lb. pressure were of inferior dessert quality because they did not attain full flavour, although they were by no means unpalatable. Lots averaging above 18 lb. tended to border on immaturity and usually became insipid in flavour and "turnipy' in texture. At room temperature, best quality for the pick, or for the class, was reached in 2 or 3 days to a week after harvest, depending on the stage of ripeness reached at picking time.

So far as flavour and texture are concerned, what has been said of peaches at room temperature is applicable, in the main, to those in continuous storage at 45° F., except that ripening proceeded more slowly, requiring 1 to 2 weeks longer. Most lots of Elberta, however, developed at 45° F. a mealy or woolly texture shortly after ripening, and, in some cases, a more or less bitter flavour. Unfavourable pre-harvest conditions tended to impair the quality of Elberta and Vedette more at 45° F. than at room temperature. The other two varieties were less affected.

During storage at 33° F., little change took place in either colour or texture until about the time breakdown appeared. Flavour was masked because of the low temperature of the fruit, but observations taken on fruit removed from storage indicated that flavour improved very slowly, if at all, at 33° F.

Figure 3 illustrates the changes in flavour observed in 1939 in peaches ripened at room temperature, either immediately after harvest, or after 10, 20 and 30 days at 33° F., or after 10 days at 45° F. Although flavour is a very good, practical criterion of quality and the one by which all dessert fruit is eventually judged, its elusive nature makes standards arbitrary and classification largely a matter of opinion, particularly with respect to the better fruit. For present purposes, therefore, each sample was tasted

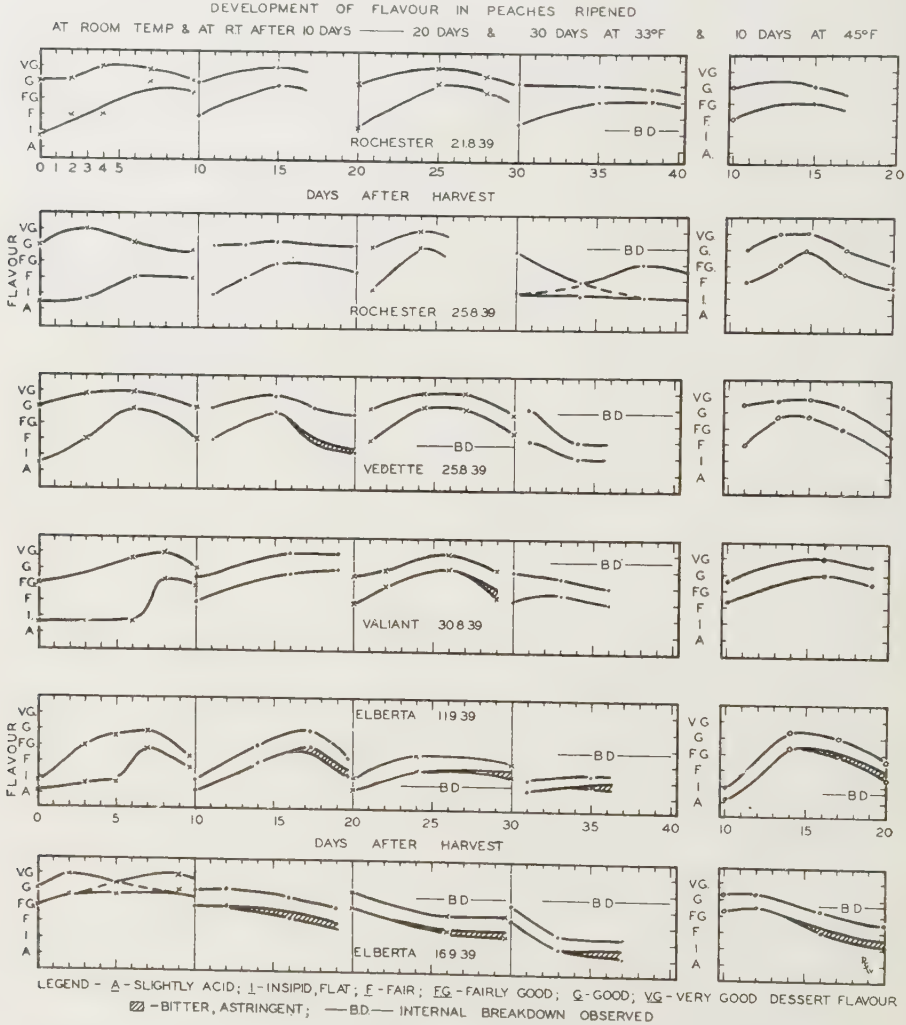
DEVELOPMENT OF FLAVOUR IN PEACHES RIPENED
AT ROOM TEMP & AT RT AFTER 10 DAYS —— 20 DAYS & 30 DAYS AT 33°F & 10 DAYS AT 45°F
VG G FG F I A
FLAVOUR
ROCHESTER 21.8.39
ROCHESTER 25.8.39
VEDETTE 25.8.39
VALIANT 30.8.39
ELBERTA 11.9.39
ELBERTA 16.9.39
BD
0 1 2 3 4 5 10 15 20 25 30 35 40
DAYS AFTER HARVEST
LEGEND - A - SLIGHTLY ACID; I - INSIPID, FLAT; F - FAIR; FG - FAIRLY GOOD; G - GOOD; VG - VERY GOOD DESSERT FLAVOUR
▨ - BITTER, ASTRINGENT; —BD— INTERNAL BREAKDOWN OBSERVED

FIGURE 3. Changes in flavour observed in 1939, in peaches at room temperature and ripened at room temperature after 10 days at 33° F. and 45° F., and after 20 and 30 days at 33° F.

by at least two observers and the range of flavours was agreed on after consultation. For the most part, the results given in Figure 3 are typical of those obtained in other years, except that, in 1939, Elberta was considerably better than usual.

For periods up to 10 days, storage at either 33° or 45° F., had no appreciable effect on the flavour of fruit ripened afterwards, except in the case of Elberta, which usually failed to attain high quality. In addition, each year some fruits in all lots of Elberta become bitter or even astringent shortly after removal, if the storage period exceeded 7 to 10 days. By way of contrast, bitterness appeared only occasionally in Vedette and Valiant (Figure 3) and rarely in Rochester. For these 3 varieties, 10 to 14 days marked the limit for satisfactory storage at 45° F., if the fruit was to be held for any length of time at room temperature.

If taken from storage at 33° F. after about 3 weeks, Rochester peaches each year ripened as well as or better than they did at room temperature after no chilling. In 1939, the same was true of Vedette and Valiant, but in 1938, though picked at ostensibly the same stage of ripeness as in 1939 (cf. Figures 1 and 2), these varieties reached only a "fairly good", in place of a "very good" flavour. This is taken to mean that, as the length of time in storage increased, Vedette and Valiant manifested their response to seasonal influences more than did Rochester with regard not only to firmness during storage, as already noted, but also to the other characteristics associated with quality and developed during post-storage ripening.

In spite of the fact that pressure changes were for the most part relatively small during the first 30 days at 33° F. (Figures 1 and 2), no lots of peaches ripened properly if removed from storage at the end of that time, for they all showed signs of breakdown soon after they were returned to room temperature, even though fairly good to good flavour was noted in Rochester and Valiant. At low temperatures, ripening, while proceeding at a low rate, evidently deviated gradually from the course normally followed at higher temperatures, so that, after a certain length of time, firmness no longer reflected keeping quality. Furthermore, the longer the peaches were held at low temperatures, the sooner they ripened and deteriorated after removal until eventually the stage was reached where the fruit deteriorated without ripening. The time required to pass that critical point varies with the variety and with the season and determines the storage life of the variety in any given year.

Three other characters, colour, texture of the flesh and amount of free juice, should be considered in so far as they too contribute to quality. These, however, did not prove to be as satisfactory criteria of quality as did flavour. Generally speaking, peaches capable of becoming full flavoured after storage were also capable of becoming juicy and well coloured, but good colour and abundant juice did not always denote good flavour. In most instances, peaches became melting in texture as they ripened unless they were firmer than 18 lb. when picked, in which case they usually became turnipy or, at best, semi-melting and somewhat stringy. An exception should be made for Elberta in which variety the juicy, melting texture was followed more or less quickly by mealiness or woolliness, particularly in lots which had been stored at low temperature for more than 10 days.

Between these two conditions there were transitional stages during which the juice was being reabsorbed and which may be described as "moist mealy". Mealiness did appear from time to time in the other varieties, but later in their storage life and to a lesser degree than in Elberta.

So far as the present experiments were concerned, in each variety of peach, quality and adaptability to storage depended not only on the stage of maturity at which they were picked, but also on the relative time of harvest. For example, peaches of the riper grade attained better flavour after storage than the greener ones of the same pick treated the same way. On the other hand, the fruit picked early in the harvest season, even though apparently less mature, either retained its ability to ripen after longer periods of storage, as in the case of Rochester (Figure 3), or ripened better, as in the case of Elberta (Figure 3), than the fruit picked towards the end of the harvest season. The implications, then, are that the first peaches to ripen are best suited to cold storage and that the significance of the tests for ripeness is modified as the picking season advances.

Internal Breakdown

Diffuse or invasive breakdown, which was the type most commonly observed in peaches, usually commenced with the appearance of minute bubbles in the intercellular spaces of the flesh, from about $\frac{1}{16}$ inch beneath the skin inwards, and advanced towards the pit until the whole flesh became involved. Aeration of the flesh was frequently accompanied or followed by a pink discoloration which very soon turned brown. Such reddening of the flesh was observed in stored peaches, but more often in lots removed to room temperature after a considerable time in the cold. In many cases, the successive stages were well separated even when overlapping but in others breakdown proceeded so rapidly that the pink flush was either very transitory or left out altogether and traces of internal browning gave the first intimation of trouble. After the development of invasive internal browning, affected areas were discernible through the skin and the fruit felt spongy and "dead". In the early stages, breakdown tended slightly to raise the resistance of the flesh to pressure and to make cutting the flesh with a knife distinctly audible. After the peaches had been a certain length of time in cold store, particularly at 33° F., the onset of breakdown was hastened by raising the temperature of the fruit, for breakdown would appear in lots ripening after storage long before it did in comparable lots left in the cold. In non-cooled peaches held at room temperature, physiological breakdown either did not occur or was obscured by internal fungal decay arising 3 to 4 weeks after harvest from infection by various moulds through the stem scar and working outwards from the pit.

A second radiating form of internal browning, less frequent and less extensive than the invasive type, originated at the pit and spread outward through the flesh. In some seasons, a reddish line in the flesh next to the pit or reddish streaks radiating through the flesh from the neighbourhood of the pit suture preceded browning. This radiating type of breakdown was of more frequent occurrence in Elberta than in the other varieties.

Small, injected, watersoaked areas were also observed, usually near the pit suture, though sometimes partly or completely around the pit.

Injected flesh of this type, too, was recorded earlier and more often in Elberta than elsewhere. Although this condition was observed in harvested fruit only after being removed from prolonged storage or late in their storage life, it does occur also in peaches left on the tree until they are overripe. In advanced stages, the injected tissues dried out to form a series of

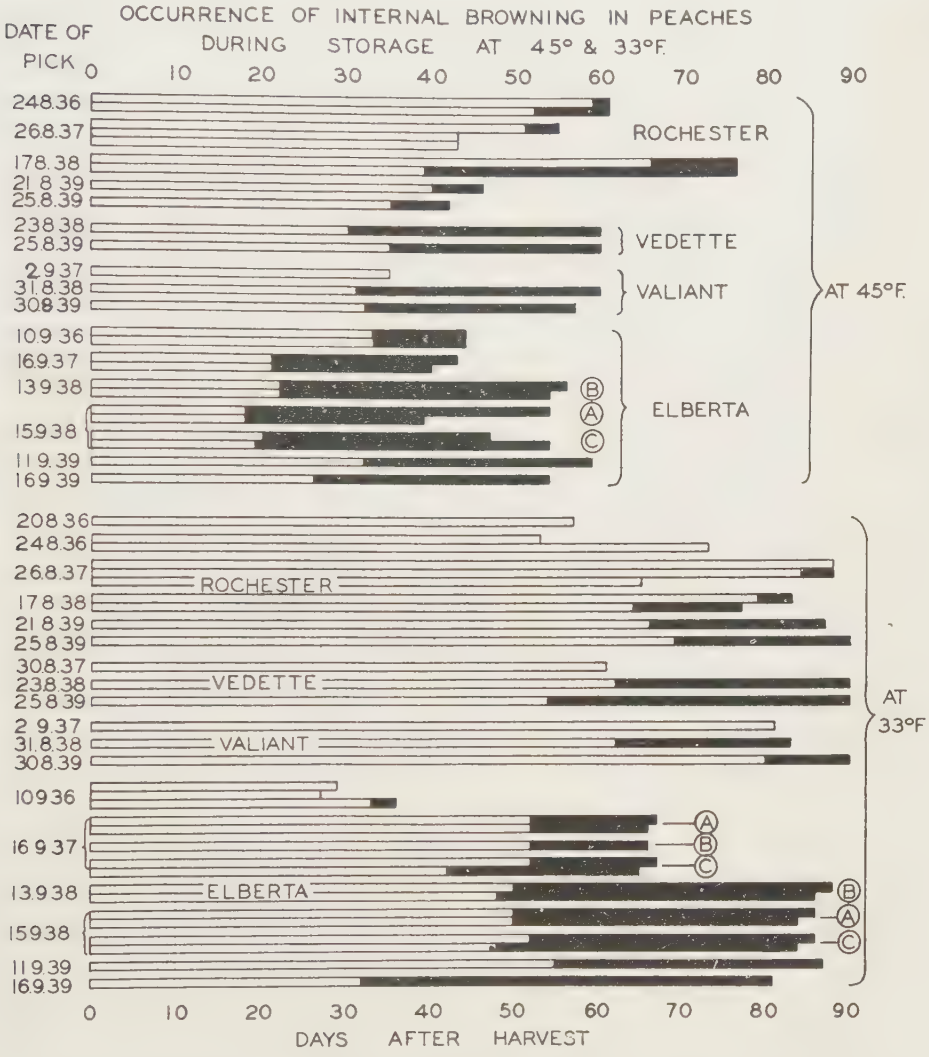

FIGURE 4. Periods (in black) during which internal browning was observed in peaches of different varieties held at 45° F. and at 33° F. in the seasons 1936 to 1939 inclusive. Peaches of the variety Elberta indicated as A, B and C, were from plots cultivated annually until June 15, July 15, and Aug. 15, respectively. Wherever two or more columns are grouped together, the lower indicates the riper lot.

lenticular cavities in the flesh next to the pit, but this usually happened after the flesh was badly affected by invasive breakdown.

Mealiness, which has already been discussed, should be considered either as a form of breakdown or as the forerunner of the invasive type of breakdown.

The time during which internal browning appeared in each of the various lots of peaches is indicated, in Figures 4 and 5, by the solid black section of each column and the period of cold storage (Figure 5) by the cross-hatched section. In these figures, wherever the columns are apparently duplicated, e.g., the Rochester pick of 26.8.37 (Figure 4) or the

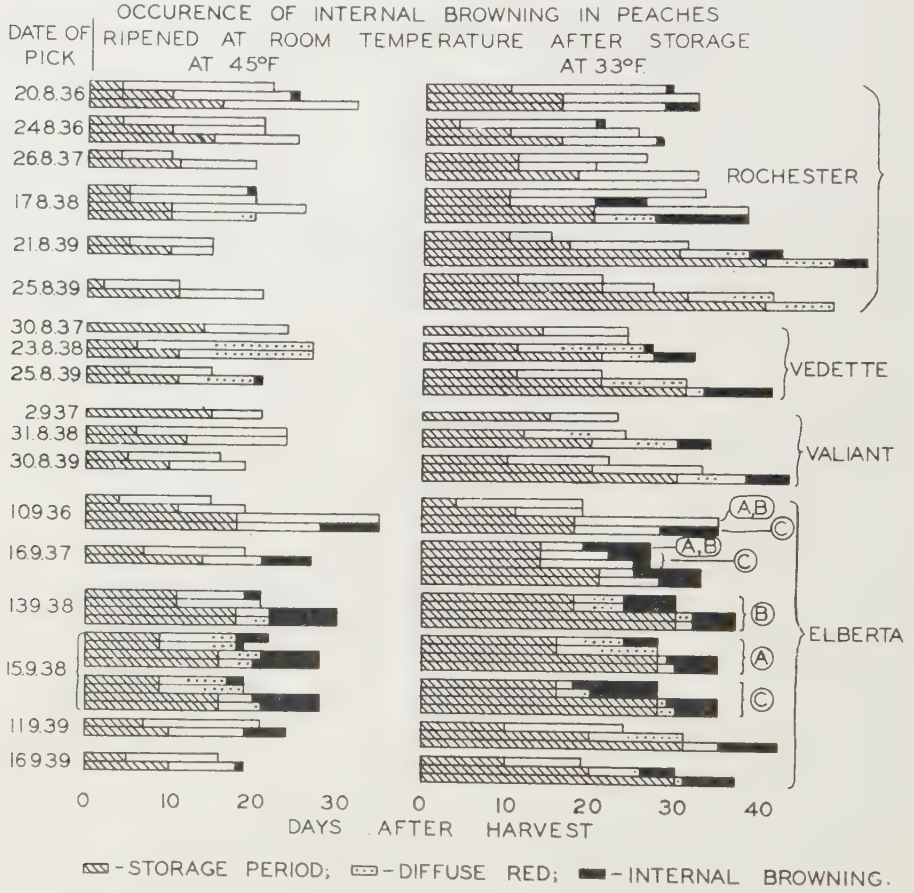

FIGURE 5. Periods during which diffuse or invasive red discoloration and internal browning were observed in peaches of different varieties ripened at room temperature after storage for various periods at 45° F. and at 33° F., in the seasons 1936 to 1939 inclusive. Peaches of the variety Elberta, indicated as A, B, and C, were from plots cultivated annually until June 15, July 15, and Aug. 15, respectively. Wherever columns are duplicated for lots from the same plot and stored for the same length of time, the lower indicates the riper peaches.

Rochester lots of 17.8.38 held respectively 5 or 10 days at 45° F., or 10 and 20 days at 33° F. (Figure 5), the lower column represents a riper stage than the one immediately above it. It should be remembered that neither the extent nor the intensity of breakdown is indicated in the charts, and may have been a trace at first, increasing in the course of time.

Of outstanding importance are the varietal differences exhibited, with regard to breakdown and the effect of the storage temperature. Elberta, for example, was affected after about *3 to 4½ weeks* at 45° F., and, except

for the last pick in 1939, after about *7 to 7½ weeks* at 33° F. In Rochester peaches, on the other hand, the time of commencement of browning varied more with the season and with ripeness at harvest and ranged from *5 to 9 weeks* at 45° F., and from *9 to 12 weeks* at 33° F. (Figure 4). Elberta also showed internal browning after shorter periods of storage and sooner after removal to room temperature (Figure 5). As a general rule the riper grades of peaches broke down somewhat earlier than the greener ones of the same pick, though there were exceptions in several lots of Elberta removed from 33° F. (Figure 5). In most instances the discoloration developed sooner after removal from 45° F. than it did after the same length of storage at 33° F. (Figure 5).

As far as breakdown was concerned, Vedette and Valiant were intermediate between Elberta and Rochester. Although these two varieties resembled one another fairly closely in behaviour, Valiant appeared to be somewhat more tolerant to storage at 33° F. than Vedette (Figures 4 and 5).

SUMMARY AND CONCLUSIONS

The application of tests for firmness of flesh, colour, and percentage of soluble solids in expressed juice as criteria of maturity and ripeness in peaches of the varieties Rochester and Elberta has been investigated since 1933. The same varieties, along with Vedette and Valiant, whose season comes in between the others, were also used in studies of peaches during and after storage at temperatures usually obtained during transportation either with or without refrigeration.

Although the concentration of soluble solids in the juice usually increased as the fruit matured, the changes were too slight, the readings too variable, and the trends too inconsistent to justify the practical use of this characteristic.

Colour alone was not a reliable guide to either maturity or picking stage, but it was very useful in grading the fruit of a given pick into lots of reasonably uniform ripeness.

Both varieties of peaches, in all but one instance, became mature, that is, would ripen more or less satisfactorily at room temperature after picking, when pressure tests on the unpeeled cheek averaged 19 to 20 lb., measured with a penetrometer having a plunger $\frac{5}{16}$ inch in diameter. After maturity was passed, peaches showed considerable variability in firmness.

For ordinary purposes average test should be from 14 to 18 lb. at harvest, and for cold storage, 10 to 14 pounds, particularly if the temperature is to be in the vicinity of 33° F. Peaches softer than that had a better flavour when ripe, either with or without previous storage, but were more subject to bruising during handling. Pressure tests, however, must be used with discrimination and not according to any hard and fast rule. They are particularly useful for determining the colour standards suitable for each pick and purpose. This is important because the relationship between colour and pressure changes varied from season to season, from orchard to orchard, and even from pick to pick.

The rate of softening of peaches after harvest was rapid at room temperature, but was decreased by lowering the temperature during the holding period. At 33° F., comparatively little change in firmness occurred

in the Rochester variety; in the others, particularly Elberta, softening proceeded more or less gradually. Weather conditions just before harvest appeared to influence not only the rate of softening during storage, but also the quality which developed afterwards.

The varieties, Rochester, Valiant and Vedette could be held, without serious effect on subsequent ripening, for periods of 10 to 14 days at 45° F., or of 3 weeks or more at 33° F. In some seasons the first two varieties developed fairly good texture and flavour after 30 days at 33° F., but began to show signs of internal breakdown shortly after removal from low temperature. Elberta, on the other hand, could not be stored for more than 10 days at 45° F., or about 2 weeks at 33° F. Bitter and astringent flavours were present in Elberta after storage at either temperature for more than about 10 days.

The first fruits of a variety to reach the proper picking stage were usually better adapted to refrigeration than those ripening towards the end of the harvest period.

Breakdown in peaches took the form of mealiness, aeration of the flesh, and internal browning. The last mentioned, which may be either invasive or radiating in type was frequently preceded by reddish discoloration of the flesh. Small areas of injected flesh at the pit also accompanied breakdown in many lots. Both at 45° F. and at 33° F. and after removal from storage, breakdown and discoloration appeared earliest and most often in Elberta and latest and least often in Rochester. Vedette and Valiant were intermediate in their reaction. In most instances, breakdown occurred somewhat earlier in the riper grade than in the greener grade of peach picked at the same time.

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CERTAIN OAT CULM CHARACTERS AND THEIR RELATIONSHIP TO LODGING[1]

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"Strength of straw" is a problem about which there has always been much controversy. Several publications dealing with the relationship of certain plant characters to lodging of grain, have appeared in the past twenty years. The inability of the crop to remain in an upright condition is of importance in the economical production of cereal crops. To the plant breeder it is likewise of prime importance in most areas, and is one of the major problems in the development of improved varieties.

In order to be able to evaluate new hybrids, strains, or selections as to their standing ability, it is necessary to know some character or association of characters which acts as an index to strength of straw. Many workers have attempted to find such an index and certain relationships have been found to exist. It is generally accepted that the factors associated with "strength" may be several and may be interrelated in various ways. This, along with the fact that environment greatly influences lodging, makes it very difficult to arrive at a satisfactory index on which to predict, within reasonable limits, the ability of the plants to resist lodging.

Present knowledge about the factors responsible for certain varieties being "strong strawed" and others being "weak strawed" is lacking in many respects. Methods to evaluate "strength of straw" seem in many ways to be unsatisfactory. This study was undertaken because of direct concern with this problem.

REVIEW OF LITERATURE

A brief review of the more important points discussed in the literature shows that results on mechanical measurements, plant character studies, chemical determinations and anatomy of the culm have been published in relation to lodging.

Mechanical Measurements and Plant Character Studies

In order to classify new strains for strength of straw, mechanical devices have been constructed to test the resistance of culms either to breaking or bending. Workers have differed in their conclusions as to the value of such methods. There appears to be skepticism as to their practical value. Other factors, or groups of factors, than breaking strength seem to be important in distinguishing strains resistant to lodging. Atkins (2) found that weight per unit length of straw was a better index of straw strength than the breaking strength method.

Brady (3), in his wheat studies, found external plant characters such as height of plant and length and diameter of lower internodes to be as reliable estimates of lodging as were internal anatomical characters. He

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has shown further that some of the stronger varieties were the heavier yielders. Also, the ability of a plant to remain erect appeared to have little association with the yield of straw.

Lodging may be greatly influenced by heavy vegetative growth and probably by having more tillers per plant (13). Garber and Olson (6) found no correlation between yield and lodging or between height of plant and lodging. None of the characters measured showed a relationship to strength of straw. It was concluded that qualitative factors were probably more important than quantitative ones.

Ramiah (11), after reviewing the literature on this problem, concluded that no one morphological aspect of the plant gave an index to lodging; also that resistance to bending of the stem was the best measure of standing power; that resistance to lodging depended not only on the length but on the elasticity of the culm and probably the number and extent of the leaves; and finally that lodging was associated with a higher average percentage of straw and longer and lighter ears and that standing was associated with less tillering.

Measurements on length of internodes, length of leaf sheath and floral parts have shown inconsistent results.

Chemical Determinations

Ashton (1) associated strength of straw with a relatively high content of certain ash constituents, particularly silicon dioxide, and with a low crude fibre content. Phillips, Davidson and Weihe (10) supported the view that lodging may be caused by a deficiency of silicon dioxide in the straw. Douglas (see 10) considered a low silica content as one of the many causes of lodging in sugar cane. The importance of silica, as an index to lodging, has often been questioned. Welton (13) was able to grow plants to maturity in nutrient solutions free of silica. Furthermore it has been pointed out, that most of the silica is in the leaves rather than in the stems. The importance of silica to this problem seems to have fallen into disrepute (3).

Low dry matter per unit length of culm has been associated with weak straw by Welton and Morris (13). Phillips, Davidson and Weihe (10) showed cellulose content to be higher in the straws of grain which lodged, except in the last stages of growth when it decreased. In the early stages of growth the ash content of the plants was higher in those which lodged. In later stages of growth the plant ash was higher in the plants which did not lodge (10).

Contrary to expectation, wheat plants which received sodium nitrate and were lodged in nearly every case, contained a higher percentage of lignin than plants which received no nitrate and where lodging had not occurred (10). These results were consistent for 2 years. The percentage lignin was even higher in the heads of the plants on the fertilized plots. Low percentage of lignin has, at times, been mentioned as being associated with weak straw. Of interest also is the work of Dadswell and Hawley (5) in which brash specimens of Douglas Fir were found to contain a higher lignin and lower cellulose content than tough wood.

Anatomy of the Culm

Histological studies of the more mature culms of cereal plants have been limited in extent. Thicker culms (3) and culm walls (6, 11), more scleren-

chyma tissue, and thicker walled sclerenchyma cells (3, 6, 11) have been reported as contributing to strength of straw. The thickness of sclerenchyma cell walls has been found to show no consistent correlation with the ability to resist lodging in barley (6). Brady (3) has reported that more lignified tissue exists in the stronger straws.

The number of vascular bundles appears to present a more distinct relationship with lodging than any other anatomical character. A higher number of vascular bundles has been found in strong straws than in weaker ones (3). Garber and Olson (6) found the spring wheats with stronger straw to have a slightly larger number of vascular bundles and a somewhat greater total area of bundles. In contrast Ramiah (11) concluded that in rice there is no relationship between lodging and the number and size of vascular bundles.

Moldenhawer (8) made an extensive study of the vascular bundles in different wheat types and found the number to be entirely characteristic for each variety. In many cases the differences were very distinct. He concluded that the erectness of cereal culms, and the comparison therewith to lodging, showed a high correlation between the number of bundles in the culm and those two factors.

Reported evidence on various plant characters which may indicate the strength of the culms is very conflicting. A good deal of this can probably be attributed to the range of plant types tested and the particular environment where tested; to the fact that studies have been made at different stages of plant maturity and on different parts of the plant; also in many cases to the small number of varieties studied and to the possibility that many characters studied have no relationship to strength of straw.

While at present certain characters may act as relative indicators to strength of straw, there is no reliable criterion of resistance to lodging. The characters generally associated with it seem to be found to a greater degree in the varieties resistant to lodging than in others. At present, the basis for selecting strains resistant to lodging is general type of straw and growth behaviour.

METHODS

Varieties of oats differ widely in their ability to remain upright and free from lodging throughout the growing season. While the amount of lodging may vary greatly from year to year, depending upon the environmental conditions under which the varieties are grown, yet certain ones are described as being strong strawed, others weak strawed, and many as being intermediate in this regard.

The varieties used in this experiment have been studied for several years in field tests in many parts of Canada. Their strength of straw can be classified as being strong, weak, or intermediate. Even when grown under the same conditions this relationship, one to the other, is quite constant. Such being the case, one would readily assume that some difference or association of differences must surely exist between them. The problem is to study these differences and attempt to associate them with the different degrees of lodging.

The field on which the varieties were grown was above average in fertility and one on which grain seemed to lodge invariably. The planting arrangement was a 10 × 10 Latin square. In addition a long strip of each variety, measuring about 75 feet × 30 feet, was planted.

At Ottawa oats usually lodge about the time of heading or a little later. At this stage of maturity several plant characters were studied. Different types of lodging can be noted. Probably the most common type of lodging is that which occurs after a heavy rain or wind storm in which the plants bend over near the ground level. A different type of lodging, characterized by a breaking of the culms a few inches above the ground level, is often noted as the crop approaches maturity.

The culm studies were mainly confined to the lower three internodes. That part between the soil level and the first above-ground node was considered as the first internode. The interval between the first and second above-ground nodes comprised the second internode. Likewise, the next internode above was the third.

When approximately 50% of the main tiller panicles in a plot had emerged from the last sheath, the height of 50 main tillers was measured. Five culms were selected from each variety replication to make up the sample of 50. The length of the three lower internodes, leaf sheaths and total number of nodes in each culm were recorded. The diameter of the culm, at the centre of each internode, was determined by means of a caliper. The culm was split at the centre of each internode and the thickness of the culm wall was determined by means of a micro-caliper. The green and dry weights of the three lower internodes were also obtained. In the field plots the percentage lodging was estimated for each variety with as much accuracy as possible by direct observation.

As soon as each plot was ripe 200 main tiller culms were cut at the ground level. By closely following the method outlined by Atkins (2) and dividing the straws into two samples, a 10-centimeter length was cut from each straw. This portion included the second node and a part on either side of it. These bundles of 10-centimeter lengths of straw were allowed to dry for several weeks to reach a uniform moisture content before weighing. Thus the weight per unit length of 100 culms was obtained. In 1939, the variety Laurel was substituted for C.D. 1625. It was not considered worth while to continue studying the number of nodes, the length of the leaf sheaths or the length of the internodes.

Unfavourable weather again caused much lodging in 1939. The grain lodged soon after heading. The differentiation between varieties in strength of straw was from one extreme to the other and very much as expected. The type of lodging and contrast between varieties is shown in Figure 1. Lodging in the larger field strips corresponded to that in the smaller plots.

At heading time several culms were selected from some of the stronger and weaker varieties. Care was taken to select representative plants. The three lower internodes were preserved for histological studies. During the winter of 1939–40, histological studies were made on the preserved culms at the University of Wisconsin. Four varieties of oats were chosen for this study. Acton and Glasnevin Ardri were selected as representing strong strawed types. The latter, derived from a cross between Glasnevin

FIGURE 1. Illustrating different degrees of lodging in the "Strength of Straw" nursery at Ottawa. Such conditions existed following a heavy rain on July 27, 1939. The variety which has remained upright is "Eagle", one of the strong strawed varieties used in this study. To the right is the variety "Don de Dieu" which is known for its weak straw. It can be noticed that most of the culms are bent over a few inches above the ground while others have fallen over at the ground level

Sonas and Victory, was obtained from University College, Dublin, Eire. It is described as perhaps the most valuable strong strawed variety in that country. Because of a small amount of seed available it was not included in the regular lodging test. It was grown alongside for comparison and appeared to be in the class with other strong strawed varieties. The culms were sturdy and it was chosen for the histological comparison. In contrast, two weak strawed types, Don de Dieu and Old Island Black represented the other extreme.

After considerable difficulty it was found that microtome cross sections of the culm could be cut. They were cut from the centres of the three internodes. The sections were stained in safranin and light green (in clove-oil). Three culms were used for each of the four varieties.

After studying many free hand and microtome sections it appeared that the second internode was the location in the culm where differences between varieties were most constant for all culms examined. The first internode was short and tough, and varied in length. It was difficult to work with. Also the second internode had been chosen before as the most representative place in the culm for field data comparisons. Measurements of several anatomical characters were made by means of an ocular micrometer.

EXPERIMENTAL RESULTS

The degree of lodging, in per cent, for each of the 10 varieties studied in 1938 and 1939 is shown in Table 1. The number of nodes per plant and the length, in inches, of the three lower internodes and leaf sheaths are given for 1938. In reference to the number of nodes per plant, the figures indicate the frequency with which a certain number of nodes, per 50 plants, occur. In addition Table 1 shows the internodal culm diameters and the thickness of the culm wall, in millimeters, for each variety studied in 1938 and 1939. The values in the last four columns of the table represent the average of 50 measurements which were made on that number of culms. The headings 1, 2, and 3 refer to the first, second and third internodes, as explained under "Methods".

The marked difference in percentage lodging between the varieties was readily noted. Moreover, the differences were quite consistent for both years and the gradation in degree of lodging from the one extreme to the other was evident.

The number of nodes per plant varied considerably within a variety. It appeared that no association existed between the number of nodes and lodging behaviour. Because of the great variation within a variety and no marked variations between varieties, this character was not studied in 1939. Although Trelle's Dwarf had fewer nodes per plant, its height was so much shorter than the others that probably it could be expected to have a small number of nodes. As the culm measurements ascended from one internode to the next, the culm diameter tended to increase. In comparison, the thickness of the culm wall tended to decrease. The length of the internodes and leaf sheaths increased markedly with each succeeding internode. In planning the statistical interpretation of the results it was considered advisable to select only one of the three internodes for detailed study.

TABLE 1.– PER CENT LODGING, NUMBER OF NODES AND MEASUREMENTS ON THREE LOWER PLANT INTERNODES FOR TEN OAT VARIETIES GROWN AT OTTAWA IN 1938 AND 1939

Variety	Per cent lodged	Number of nodes				Diameter of culm in mm.			Thickness of culm wall in mm.			Length of internode in inches			Length of leaf sheaths in inches		
		3	4	5	6	1	2	3	1	2	3	1	2	3	1	2	3
1938																	
Trelle's Dwarf	0	11	39	0	0	3.4	3.9	4.3	.97	1.00	.87	1.4	2.5	5.6	4.2	5.2	5.7
Eagle	9	0	29	21	0	4.3	4.8	4.6	1.26	1.19	.95	2.1	4.3	6.2	4.6	4.8	5.0
Great Mogul	9	0	9	34	7	4.3	4.9	5.3	1.49	1.31	1.13	1.6	2.9	4.5	4.0	4.7	5.2
Waterloo	9	0	13	37	0	4.1	4.5	4.5	1.37	1.31	1.08	2.0	3.3	5.8	4.0	4.6	5.1
Acton	10	0	0	46	4	4.3	4.7	5.3	1.44	1.38	1.22	2.0	2.8	5.9	4.7	5.3	5.7
Victory	30	0	0	34	16	4.7	5.3	5.6	1.35	1.22	1.09	2.4	4.5	5.7	4.5	5.1	5.7
White Cross	35	0	0	50	0	3.1	3.8	4.1	.94	.91	.87	1.5	2.6	3.9	3.2	4.4	5.1
C.D. 1625	40	0	4	44	2	3.5	4.0	4.0	1.11	1.04	.96	3.0	4.1	4.2	3.9	3.9	4.2
Don de Dieu	99	0	2	43	5	3.7	3.9	4.3	1.14	1.16	1.06	2.4	3.7	5.3	4.7	5.2	5.4
Old Island Black	99	0	0	36	14	3.9	4.3	4.5	1.20	1.13	1.02	2.3	3.6	4.6	4.3	4.7	4.8
1939																	
Trelle's Dwarf	0					3.9	4.2	4.4	1.00	.96	.93						
Eagle	11.8					4.1	4.6	4.8	1.16	1.12	1.00						
Acton	15.0					4.0	4.5	4.8	1.20	1.17	1.12						
Laurel	15.0					4.1	4.6	4.7	1.22	1.15	1.01						
Great Mogul	29.5					4.0	4.5	4.5	1.13	1.14	1.05						
Victory	41.8					4.1	4.6	4.7	1.17	1.11	1.06						
Waterloo	47.7					4.2	4.7	4.9	1.20	1.13	1.09						
White Cross	55.2					3.7	4.2	4.4	.94	.88	.85						
Don de Dieu	98.2					3.5	3.9	3.9	1.02	.96	.92						
Old Island Black	98.2					3.2	3.6	3.6	.86	.86	.84						

Statistical Analysis of Culm Measurements and Lodging

The simple or total correlation coefficients between percentage lodging and the measurements of Table 1 were calculated. The values of r in measuring the relationship between percentage lodging and length of internode and also leaf sheath have proved non-significant and are not presented. The more important correlations are to be found in Table 3. In 1938, the correlations between lodging and both diameter of culm and thickness of culm wall were negative but not significant. These negative values indicated that there was a trend toward a relationship between high lodging and low diameter of culm and thickness of culm wall. In 1939, negative correlations were again obtained between percentage lodging and diameter of culm. They were highly significant at each internode. Although the correlations between lodging and thickness of culm wall were not significant, they were quite high. The differences shown between the two years were, no doubt, due to the variation in the degree of lodging which might be expected from year to year. In correlating only 10 pairs of figures, relationships must be very closely associated to prove significant.

After examining the above relationships and taking into consideration the fact that measurements were easier to make at the second internode than at the first and that the third internode came quite high in the culm, the second internode was chosen as the position to use for further statistical study of the data.

Table 2.—Six measurements used for detailed analysis of the varieties in 1938 and 1939

Variety	1 Height of main tiller	2 Diameter of culm, 2nd internode	3 Thickness of culm wall, 2nd internode	4 Weight per unit length of culm	5 Dry matter	6 Lodging
	inches	mm.	mm.	gm.	%	%
1938						
Trelle's Dwarf	19.7	3.9	1.00	7.37	27.99	0
Eagle	32.6	4.8	1.19	10.77	17.72	9
Great Mogul	37.3	4.9	1.31	11.06	23.52	9
Waterloo	36.0	4.5	1.31	10.45	21.05	9
Acton	40.8	4.7	1.38	14.02	21.03	10
Victory	47.6	5.3	1.22	12.79	19.52	30
White Cross	33.9	3.8	.91	9.46	23.29	35
C.D. 1625	38.6	4.0	1.04	7.09	22.17	40
Don de Dieu	40.9	3.9	1.16	9.14	22.85	99
Old Island Black	43.3	4.3	1.13	7.96	24.72	99
1939						
Trelle's Dwarf	27.1	4.2	.96	9.21	21.29	00.0
Eagle	39.0	4.6	1.12	9.67	18.10	11.8
Acton	44.5	4.5	1.17	12.68	20.82	15.0
Laurel	39.6	4.6	1.15	11.86	21.11	15.0
Great Mogul	44.4	4.5	1.14	12.97	26.06	29.5
Victory	45.9	4.6	1.11	12.41	23.57	41.8
Waterloo	41.0	4.7	1.13	12.97	20.42	47.7
White Cross	40.1	4.2	.88	10.51	23.46	55.2
Don de Dieu	44.5	3.9	.96	9.40	23.83	98.2
Old Island Black	44.3	3.6	.86	8.31	26.77	98.2

TABLE 3.—SIMPLE CORRELATION COEFFICIENTS FROM THE DATA IN TABLE 2.

1938		1939	
$r_{12} = +.468$	$r_{26} = -.360$	$r_{12} = -.023$	$r_{26} = -.726$
$r_{13} = +.432$	$r_{34} = +.742$	$r_{13} = +.204$	$r_{34} = +.793$
$r_{14} = +.438$	$r_{35} = -.472$	$r_{14} = +.363$	$r_{35} = -.491$
$r_{15} = -.501$	$r_{36} = -.228$	$r_{15} = +.430$	$r_{36} = -.616$
$r_{16} = +.502$	$r_{45} = -.622$	$r_{16} = +.534$	$r_{45} = -.132$
$r_{23} = +.731$	$r_{46} = -.376$	$r_{23} = +.876$	$r_{46} = -.388$
$r_{24} = +.769$	$r_{56} = +.167$	$r_{24} = +.793$	$r_{56} = +.643$
$r_{25} = -.622$	$r_{26\cdot1} = -.780$	$r_{25} = -.623$	$r_{26\cdot1} = -.845$
	$r_{16\cdot2} = +.752$		$r_{16\cdot2} = +.753$
	$R_{6\cdot12345} = +.903$		$R_{6\cdot12345} = +.923$

NOTE—
r at 5% level of significance and 8 degrees of freedom = 0.632.
r for partial correlation coefficient at 5% level of significance and 7 degrees of freedom = 0.666.
R at 5% level of significance and 4 degrees of freedom = 0.942.

Additional data for the two years are presented in Tables 2 and 3. The values in the first three columns of Table 2 are the average figures as calculated from the 50-culm measurements for each variety. In Table 3 the simple correlation coefficients have been calculated for all combinations of values appearing in Table 2. Of primary importance are those which express the relationship between lodging and the five other characters.

After a detailed examination of Table 3, certain trends were noted as: that taller plants, thinner culms and culm walls, lower weight per unit length of culm, and higher percentage dry matter may be of importance in increasing the amount of lodging, but the coefficients were not sufficiently high to prove clearly that such relations existed. Between other sets of characters various relationships existed.

The partial correlation coefficients have shown that the association between lodging and culm height is greater when culm diameter remains constant. Similarly the association between lodging and culm diameter is increased when the effect of culm height is eliminated.

The multiple correlation coefficients, indicated by R, measured the combined effect of the five characters on lodging. The values of R were large but did not reach the point of significance. Therefore the relationship between lodging and the five independent varietal characters in Table 2 was not large enough to escape the possibility of having occurred by chance.

The simple correlation coefficients have revealed the relative importance of the factors which acted upon lodging as compared to the totality of the factors at work. Since several characters were correlated with lodging independently, the variability of one might have masked the effect of another. The influence of one character may be partly expressed by another. If at all possible, it was desirable to measure the effect of one character or of an association of characters on lodging. By means of Mosak's (9) method, using simple correlation coefficients, the partial and multiple correlations of the five characters, keeping lodging as the dependent variable, were obtained. Then by analysis of variance, the significance of the relationship of the individual characters and various combinations of characters to lodging, was tested. The analysis of variance for the 1938 data that appeared in Table 2 is given in Table 4.

The above method for analysis of variance was similar to that used by Goulden (7, p. 239). In the table, the regression x_1 is the regression due to diameter of culm, alone, on lodging. That due to x_1 and x_2 expresses the regression due to the combined effect of x_1 and x_2 on lodging. The next step measures the significance of the gain in information as the result of adding the variable x_2. The regression due to x_3 accounts for any additional regression of thickness of culm wall, on lodging, which is not already accounted for by x_1 and x_2. And in a similar way to the latter, x_4 and x_5 represent weight per unit length of culm and percentage dry matter respectively.

The first two characters appearing in the analysis of variance table were chosen as the main characters on which to base the others for two reasons. First, they were as highly correlated with lodging as any other characters in 1938; and second, their simplicity of measurement was greatly in favour of their use. If a relationship suggesting an index to lodging could be established, then it would be of much importance.

By comparing the F values in Table 4, it can be readily seen that the regression due to height of main tillers alone on percentage lodging was non-significant. Likewise that due to diameter of culm was non-significant.

TABLE 4.—ANALYSIS OF VARIANCE OF 1938 DATA APPEARING IN TABLE 2

Source	Sum of squares	Degrees of freedom	Variance	F value	5% point
Total $\Sigma(x_6 - \bar{x}_6)^2$	12110.00	9			
Regression due to $x_1 = r^2_{6\cdot 1}\,\Sigma(x_6 - \bar{x}_6)^2$	3050.28	1	3050.28	2.69	5.32
Error $= (1 - r^2_{6\cdot 1})\Sigma(x_6 - \bar{x}_6)^2$	9059.72	8	1132.47		
Regression due to $x_2 = r^2_{6\cdot 2}\,\Sigma(x_6 - \bar{x}_6)^2$	1573.15	1	1573.15	1.19	5.32
Error $= (1 - r^2_{6\cdot 2})\Sigma(x_6 - \bar{x}_6)^2$	10536.85	8	1317.11		
Regression due to x_1 and $x_2 = R^2_{6\cdot 12}\,\Sigma(x_6 - \bar{x}_6)^2$	8543.04	2	4271.52	8.38	4.74
*$R^2_{6\cdot 12}\,\Sigma(x-\bar{x}_6)^2 - r^2_{6\cdot 1}\,\Sigma(x_6-\bar{x}_6)^2$	5492.76	1	5492.76	10.77	5.59
$(1 - R^2_{6\cdot 12})\,\Sigma(x - \bar{x}_6)^2$	3566.96	7	509.56		
Regression due to $x_3 = (R^2_{6\cdot 123} - R^2_{6\cdot 12})\Sigma(x_6-\bar{x}_6)^2$	47.01	1	47.01	.08	5.99
Error	3519.95	6	586.66		
Regression due to $x_4 = (R^2_{6\cdot 1234} - R^2_{6\cdot 123})\Sigma(x_6-\bar{x}_6)^2$	805.65	1	805.65	1.48	6.61
Error	2714.29	5	542.86		
Regression due to $x_5 = (R^2_{6\cdot 12345} - R^2_{6\cdot 1234})\Sigma(x_6-\bar{x}_6)^2$	108.61	1	108.61	.17	7.71
Error	2605.68	4	651.42		

* Sum of squares due to fitting the additional degree of freedom arising from the regression of x_2 on x_6.

TABLE 5.—ANALYSIS OF VARIANCE OF 1939 DATA APPEARING IN TABLE 2

Source	Sum of squares	Degrees of freedom	Variance	F value	5% point
Total $\Sigma(x_6 - \bar{x}_6)^2$	10808.16	9			
Regression due to $x^2 = r^2_{6\cdot 2}\,\Sigma(x_6 - \bar{x}_6)^2$	5703.03	1	5703.03	8.94	5.32
Error $(1 - r^2_{6\cdot 2})\,\Sigma(x_6 - \bar{x}_6)^2$	5105.13	8	638.14		
Regression due to $x^1 = (R^2_{6\cdot 12} - R^2_{6\cdot 2})\,\Sigma(x_6 - \bar{x}_6)^2$	2895.69	1	2895.69	9.17	5.59
Error	2209.44	7	315.63		
Regression due to $x_3 = (R^2_{6\cdot 123} - R^2_{6\cdot 12})\Sigma(x_6 - \bar{x}_6)^2$	541.08	1	541.08	1.95	5.99
Error	1668.36	6	278.06		
Regression due to $x_4 = (R^2_{6\cdot 1234} - R^2_{6\cdot 123})\Sigma(x_6 - \bar{x}_6)^2$	0.28	1	0.28	.0008	6.61
Error	1668.08	5	333.62		
Regression due to $x_5 = (R^2_{6\cdot 12345} - R^2_{6\cdot 1234})\Sigma(x_6 - \bar{x}_6)^2$	78.23	1	78.23	.1968	7.71
Error	1589.85	4	397.46		

But, when the regressions due to the above two characters were combined, then the F value was significant. Thus, the effect of height alone on lodging was not significant, nor was the effect of culm diameter, alone, significant. However, each contributed an appreciable part so that when the combined effect of the two was measured, the regression was significant. The sum of squares due to fitting the additional degree of freedom arising from the regression of x_2 on x_6 was significant. This showed that the effect of the diameter of culm on lodging was significant when measured independently of plant height.

Considering the regression due to thickness of culm wall, in addition to any effect which may have been expressed by height or culm diameter, it was shown by the F value to be of no significance whatsoever. Likewise the regressions due to weight per unit length of culm and percentage dry matter were non-significant. The interpretation of Table 4 is that when the effect of height of main tillers and culm diameter on lodging was taken into account no additional information was secured by bringing in the other three characters.

A similar analysis of variance for the 1939 data is presented in Table 5 Diameter of culm gave the highest correlation with lodging for this year. Since it was significant, the regression due to that character was determined first. The regression of diameter of culm alone on lodging was significant as determined by the F value. Similarly the regression of the height of main tiller on lodging, above that already explained by diameter of culm.

was significant. As in 1938, the regressions for thickness of culm wall, weight per unit length of culm and percentage dry matter on lodging were much too low to be significant. Therefore, any additional effect, on lodging, not already accounted for by diameter of culm and height could not be attributed to wall thickness, weight per unit length or dry matter.

It must be realized that the amount of lodging, although generally consistent for the varieties tested, is subject to variation from year to year. This is most likely due to the varying influence of environmental factors. Although the results present essentially the same interpretation for the two years, the slight variation from year to year was readily noted.

By far the greater part of the relationship between the five characters and lodging can be explained by the height of the main tiller and thickness of the culm at the second internode. While each may or may not be significant alone, depending upon the results of a single year, yet the two acting together show a marked association with percentage lodging as measured under natural field conditions. The other three characters at times may be quite highly correlated with lodging, yet, they do not seem to show any additional relationship above that already expressed by height and culm diameter. Also, as emphasized before, the latter two characters are very easily determined.

Chemical Analysis of Culm Tissues

A measure of the structural compounds in the culms is of importance in a study of this problem. So far, it has only been possible to analyze for lignin, sand, silica, and pentosans. A study of the cellulose compounds in the culm seems advisable. Table 6 contains the results of chemical analysis for 1938–39. Pentosan determinations were not made in 1938. Percentage sand represents that part of the silica not soluble in acid or alkali. Percentage SiO_2 represents the alkali soluble SiO_2.

The percentage of lignin for 1939 was much higher than that for 1938. Why such should be the case cannot readily be explained. Probably environmental differences in the two years may be responsible.

The simple correlation coefficients between certain of these characters are given in Table 7. Between percentage lodging and percentage lignin there was quite a marked relationship as shown by the correlations. The value of r for 1938 was high but not significant. In 1939 r was barely significant. If, as in many studies between various characters and lodging, only the extreme lodging types had been tested, then very significant correlations would result. Such correlations would not present as reliable a picture as when varieties with different degrees of lodging behaviour were tested. The relationship between lodging and lignin pointed to a definite trend for culms containing a high percentage of lignin to be severely lodged. Likewise the reverse was true. These results substantiated those obtained by Phillips *et al.* (10) with lodged wheat plants. Probably the high percentage of lignin tended to make the culms more brittle and hence induced more lodging.

The correlations between lodging and sand were not significant. No association was revealed between lodging and silica in 1938 but in 1939 there was a negative significant correlation. Silica has been described as a

variable substance in the plant. The occurrence of any relationship between silica and lodging was inconsistent and hence very little value was given to the determination of silica. Pentosans did not seem to be related to lodging.

The correlation values for the two important plant characters, height and culm diameter, with lignin, are given in Table 7. There appeared to be much more association between height and lignin than between diameter of culm and lignin. However, the percentage lignin was not determined for the whole plant but only for the three lower internodes. Likewise thickness of culm represented only the second internode and not the three internodes from which the lignin was taken.

TABLE 6.—CHEMICAL ANALYSES* OF THE LOWER THREE INTERNODES AND SUBTENDING NODES OF TEN OAT VARIETIES GROWN AT OTTAWA IN 1938 AND 1939

Variety	Lignin	Sand	SiO_2	Pentosans	Lodging
	%	%	%	%	%
1938					
Trelle's Dwarf	10.82	.23	.78		0
Eagle	12.83	.26	.87		9
Great Mogul	12.07	.19	.72		9
Waterloo	12.83	.10	.59		9
Acton	13.25	.17	.78		10
Victory	16.69	.18	.95		30
White Cross	14.79	.16	.65		35
C.D. 1625	16.15	.18	.49		40
Don de Dieu	13.87	.16	.82		99
Old Island Black	16.01	.19	.65		99
1939					
Trelle's Dwarf	18.01	.394	.779	21.93	0
Eagle	17.75	.175	.673	24.60	11.8
Acton	17.36	.167	.505	24.42	15.0
Laurel	20.41	.101	.499	23.53	15.0
Great Mogul	20.15	.179	.515	22.57	29.5
Victory	18.68	.419	.613	23.19	41.8
Waterloo	18.67	.119	.517	24.95	47.7
White Cross	19.07	.127	.577	23.99	55.2
Don de Dieu	21.12	.114	.395	23.42	98.2
Old Island Black	20.01	.099	.459	23.64	98.2

* Expressed as per cent of dry matter.

TABLE 7.—CORRELATION OF LODGING WITH CHEMICAL ANALYSES GIVEN IN TABLE 6.

Simple correlation coefficients between:	1938	1939
	r	r
Lodging and lignin	+.561	+.631
Lodging and sand	−.169	−.423
Lodging and silica	−.097	−.690
Lodging and pentosans		+.132
Height and lignin	+.758	+.338
Diameter of culm and lignin	+.087	−.458

NOTE.—r at 5% level of significance and 8 degrees of freedom = 0.632.

Again making use of Mosak's method for separating or combining the effects of different variables, the percentage lignin, height of main tillers and diameter of the culm were combined in an analysis of variance table. The analysis of variance tables are not presented.

The results for both years show that in measuring the relationship of the three characters to lodging, percentage lignin did not give any appreciable additional information above that already given by height and culm diameter.

The above results may seem strange. They must only mean that the effect of lignin on lodging, as brought out by the quite high simple correlation coefficient, was already being explained by either height of main tiller or thickness of the culm at the second internode. It may be that thinner straws which are more apt to lodge produced a higher percentage of lignin and that thicker straws produced less. It may also mean that tall plants, tending to lodge, produced a higher percentage of lignin in their lower three internodes, and that shorter plants produced less. Both assumptions may apply in part. The results also showed the various interrelationships which may exist between different plant characters.

Histological Studies of Culm Anatomy

An attempt was made to study in a systematic way, the internal culm anatomy of weak and strong strawed varieties. The procedure followed in this investigation has been outlined in the section under "Methods". As was stated, four varieties were studied by making cross sections at three positions in the culm. Three representative culms were selected for each variety. Glasnevin Ardri and Acton represented varieties which do not lodge readily. Old Island Black and Don de Dieu represented varieties which do lodge readily. In all, 12 anatomical characters were studied; 48 microtome sections were examined for each character in each variety. The photomicrographs in Figures 2 to 7, show portions of culm cross-sections of the three internodes studied in each variety.

Wide differences for several characters were noted between varieties and between positions in a culm. Other characters showed very little difference throughout. In order to interpret the results, the values obtained for each character were subjected to analysis of variance.

Only the mean values of the 12 characters measured are presented in Table 8. Where significant differences between varieties or positions have been found to exist, the mean significant differences have been calculated and recorded. The *F* values, as determined by the analyses of variance, are to be found in Table 9 for the 12 characters. The significance of the variances due to varieties, positions and the interaction, varieties × positions, can be readily checked from this table. The headings A to L in Table 9 each correspond to one of the characters.

Evaluation of Anatomical Characters

A—**Width of Sclerenchyma Layer*

The sclerenchyma layer which is composed of thick-walled, lignified cells, occurs near the periphery of the culm. In the first internode there

* Corresponds to A in Table 9.

TABLE 8.—THE MEAN VALUES AND MEAN SIGNIFICANT DIFFERENCES FOR TWELVE ANATOMICAL CHARACTERS AT THREE POSITIONS IN CULMS OF FOUR VARIETIES

Characters measured	Position on culm	Varieties				Mean[1]	M.S.D.[1]
		Ardri	Old Is. Black	Don de Dieu	Acton		
A. Width of sclerenchyma layer (microns)	1	131.9	124.7	88.1	116.7	115.4	18.0
	2	96.8	83.7	76.1	103.3	90.0	
	3	94.2	71.8	64.5	77.6	77.0	
	Mean[2]	107.7	93.4	76.3	99.2		
	M.S.D.[2] =	20.9					
	M.S.D.[3] =	36.1					
B. Width of culm wall (microns)	1	980.2	819.9	839.6	1050.5	922.5	119.6
	2	761.2	692.8	646.3	828.3	732.2	
	3	785.2	623.5	567.0	756.2	682.9	
	Mean[2]	842.2	712.1	684.3	878.3		
	M.S.D.[2] =	138.1					
	M.S.D.[3] =	239.1					
C. Diameter of hollow centre (microns)	1	1950.3	1682.0	1551.5	1631.3	1703.8	268.7
	2	2675.3	2080.7	2254.8	2461.4	2368.1	
	3	2827.5	2494.0	2494.0	3045.0	2715.1	
	Mean[2]	2484.4	2085.6	2100.1	2379.2		
	M.S.D.[2] =	310.3					
	M.S.D.[3] =	537.4					
D. Number of sclerenchyma cell layers	1	6.5	5.7	5.0	6.0	5.8	
	2	6.4	6.1	5.4	6.8	6.2	
	3	6.2	5.5	4.9	5.9	5.6	
	Mean[2]	6.4	5.7	5.1	6.2		
	M.S.D.[2] =	.79					
	M.S.D.[3] =	.43					
E. Number of cell layers in culm wall	1	21.3	20.6	19.3	22.8	21.0	1.8
	2	18.3	16.6	14.9	18.8	17.1	
	3	18.1	15.3	14.2	16.8	16.1	
	Mean[2]	19.3	17.5	16.1	19.5		
	M.S.D.[2] =	2.0					
	M.S.D.[3] =	3.5					
F. Radial diameter of vascular bundles (microns)	1	223.3	203.7	193.6	223.3	211.0	
	2	202.3	190.7	189.2	222.9	201.3	
	3	216.8	187.7	194.3	218.2	204.3	
	Mean[2]	214.1	194.0	192.4	221.5		
	M.S.D.[2] =	12.5					
	M.S.D.[3] =	21.7					
G. Width of vascular bundles (microns)	1	174.7	171.1	153.7	180.5	170.0	
	2	164.9	170.8	156.6	178.4	167.7	
	3	166.8	160.2	156.6	168.9	163.1	
	Mean[2]	168.8	167.4	155.7	175.9		
	M.S.D.[2] =	10.3					
	M.S.D.[3] =	17.9					
H. Number of lignified cells in bundle sheath.	1	52.1	49.3	42.4	44.3	47.0	
	2	45.2	41.9	41.0	48.2	44.1	
	3	46.0	42.2	41.4	46.0	43.9	
	Mean[2]	47.8	44.5	41.6	46.2		
	M.S.D.[2] =	4.0					
	M.S.D.[3] =	6.9					
I. Number of lignified cells inside the bundles	1	9.9	11.9	10.0	11.3	10.7	
	2	12.5	11.6	10.3	10.6	11.3	
	3	10.0	11.7	9.9	10.9	10.6	
	Mean[2]	10.8	11.7	10.1	10.9		

TABLE 8.—THE MEAN VALUES AND MEAN SIGNIFICANT DIFFERENCES FOR TWELVE ANATOMICAL CHARACTERS AT THREE POSITIONS IN CULMS OF FOUR VARIETIES —*Concluded*

Characters measured	Position on culm	Varieties				Mean[1]	M.S.D.[1]
		Ardri	Old Is. Black	Don de Dieu	Acton		
J. Number of vascular bundles in parenchymatous area of culm.	1	35.7	28.0	32.0	32.7	32.1	1.9
	2	40.3	33.0	30.0	40.0	35.8	
	3	40.3	34.0	33.3	37.7	36.3	
	Mean[2]	38.8	31.7	31.8	36.8		
	M.S.D.[2] =	2.2					
	M.S.D.[3] =	3.8					
K. Number of vascular bundles in sclerenchyma layer	1	19.3	16.5	18.4	18.7	18.2	
	2	19.4	17.7	17.7	18.8	18.4	
	3	17.9	16.8	16.2	18.4	17.3	
	Mean[2]	18.9	17.0	17.4	18.7		
L. Ratio of width of sclerenchyma layer to width of culm wall	1	7.5	6.8	9.9	9.5	8.4	
	2	7.9	8.4	8.7	8.1	8.3	
	3	8.4	8.8	9.0	10.1	9.1	
	Mean[2]	7.9	8.0	9.2	9.2		

NOTE—
Mean[1] = mean of twelve (3 culms, 4 varieties) culm measurements for each position.
Mean[2] = mean of nine (3 culms, 3 positions) culm measurements for each variety.
Positions 1, 2, and 3 each represent the mean of all culm measurements per variety at the first, second and third internodes respectively.
M.S.D.[1]—between positions over all varieties.
M.S.D.[2]—between varieties over all positions.
M.S.D.[3]—between varieties within a position; between positions within a variety.

TABLE 9.—*F* VALUES FROM ANALYSES OF VARIANCE ON MEASUREMENTS OF TWELVE ANATOMICAL CULM CHARACTERS

Source	Characters studied												5% point of significance
	A*	B	C	D	E	F	G	H	I	J	K	L	
Varieties	3.46	4.07	3.56	4.39	5.13	11.44	5.64	3.77	2.66	22.84	2.45	2.98	3.01
Positions	9.94	9.54	31.16	1.28	18.10	1.78	1.30	2.23	.85	12.75	1.27	1.32	3.40
Varieties × positions	.50	.17	.72	.17	.33	.64	.51	1.46	1.16	2.53	.36	3.18	2.51

* Corresponds to A. page 660.

was more sclerenchyma tissue than in either the second or third internode (Figures 2 to 7). Between the second and third internodes this area of cells was found to lie directly against the epidermal cells. However, in the first internode, there were invariably three or four layers of thin-walled cells at the outside of the culm with the sclerenchyma layer situated within and adjacent to these.

The results have shown that certain varieties differ significantly in thickness of sclerenchyma tissue. The differences, in all cases, were not in the order of straw strength.

B—*Width of Culm Wall.*

The width of the culm wall is the distance from the epidermis to the hollow centre of the culm. The results for this character, as with others, suggested that the strong strawed varieties differ from the weak strawed ones. It was also noticed that these varietal character differences may vary somewhat from one internode to another (Figures 2 to 7). It may be well to emphasize that although certain differences existed, no character could be of practical value in this study unless the differences were clear cut.

C—*Diameter of Hollow Centre*

There was a definite tendency for the strong varieties to have culms with wider hollow centres, especially in the second and third internodes. However, the differences in this regard between Acton and the weak varieties were not significant. As would be expected the diameter of the hollow centre increased significantly from one internode to another on the basis of the position means. Within a variety the increase may not always be significant.

D—*Number of Sclerenchyma Cell Layers*

The number of cell layers making up the sclerenchyma tissue did not differ between the weak varieties. Likewise, the two strong varieties did not differ. The weak varieties, however, differed significantly from the strong ones. No difference was noted between positions. While this character may have some association with strength of straw, the differences were not great. Too much emphasis could not be placed upon this character as a possible lodging index especially as all varieties may differ significantly from one another at different culm positions.

E—*Number of Cell Layers in Culm Wall*

The average number of cell layers making up the culm wall was greater in the strong varieties than in the weak varieties. Yet between the strong variety Ardri and the weak variety Old Island Black, the difference was not a significant one. Position had an effect on this measurement, showing the values at the first internode to be higher than the others.

F—*Radial Diameter of Vascular Bundles*

Considering all varieties, the radial diameter (diameter perpendicular to culm epidermis) of the vascular bundles did not differ from one internode to another (Figures 2 to 7). In this case the varietal means differed significantly. The two weak varieties did not differ from each other,

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FIGURES 2 AND 3. Portions of microtome cross-sections, which represent the centre of the first internode of the culm. Weak-strawed varieties, Don de Dieu (A) and Old Island Black (C) contain 29 and 28 vascular bundles respectively. Strong-strawed varieties, Acton (B) and Glasnevin Ardri (D) each contain 35 bundles. Also, the strong-strawed varieties have larger (greater radial diameter) vascular bundles than do the weak varieties. The thickness of the culm walls is noticeably greater in the varieties Acton and Ardri. This difference was not as marked in all culms studied. Other culm differences do not appear to be associated with lodging. Sclerenchyma cell layer is not adjacent to the epidermis as in the second and third internodes. ×82.

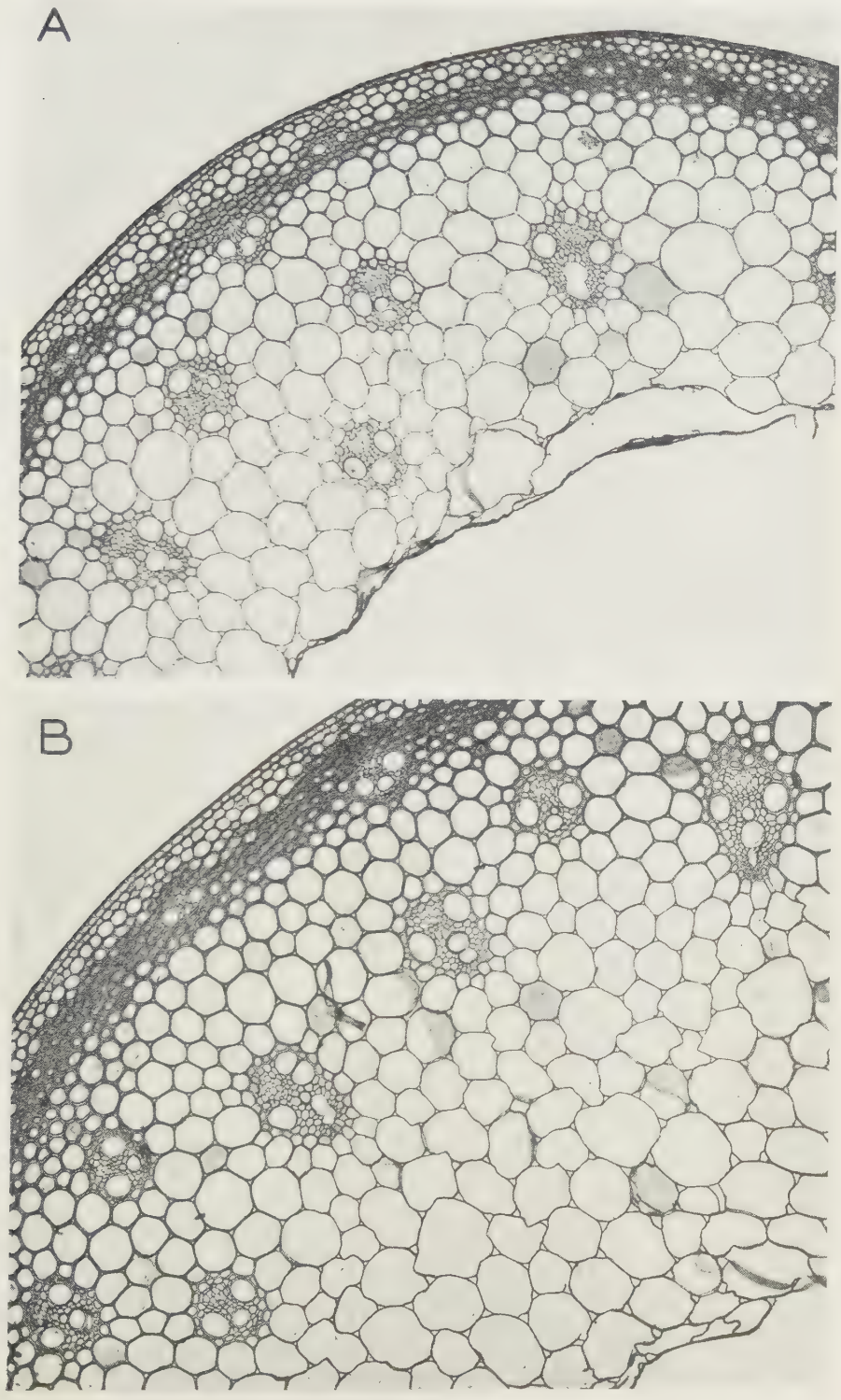

FIGURE 2.

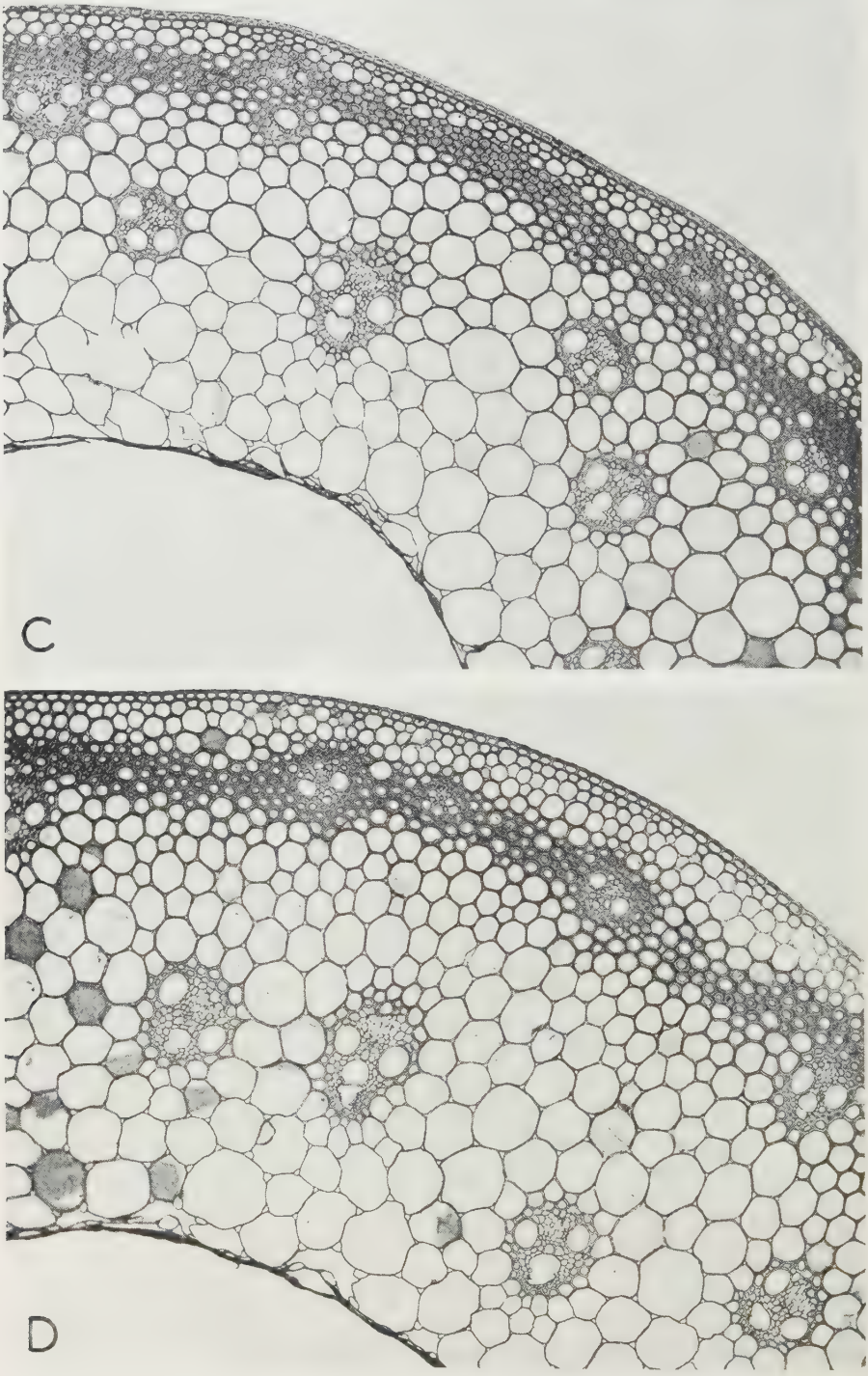

FIGURE 3.

nor did the strong varieties differ from each other. Of importance was the difference shown between weak and strong varieties. The fact that the strong varieties had vascular bundles which were greater in radial diameter than those of the weak ones may be very interesting and of value especially when the number of bundles is considered.

G—*Width of Vascular Bundles*

The width (diameter parallel to culm epidermis) of the same vascular bundles, likewise did not vary significantly from one internode to another (Figures 2 to 7). The weak varieties differed significantly from each other in respect to the varietal means over all positions. At the second and third internodes this difference was not apparent. Old Island Black did not differ significantly from either strong variety. Width of vascular bundles by no means presented the same relationship to straw strength as did radial diameter of bundles.

H—*Number of Lignified Cells in Bundle Sheath*

The number of thick-walled, safranin stained cells making up the bundle sheath did not vary significantly from internode to internode. While Don de Dieu appeared to differ from Ardri and Acton when all position measurements were averaged, Old Island Black did not seem to differ from either.

I—*Number of Lignified Cells Inside the Bundles*

In this case, the number of thick-walled, safranin stained cells inside the bundle was determined. No differences were found to exist between varieties or between positions.

J—*Number of Vascular Bundles in Parenchymatous Area of Culm*

When the cross-sections were being examined, it was noted that the number of vascular bundles was much greater in the culms of the strong varieties than in the weak types. This determination comprised those vascular bundles situated in the parenchymatous area of the culm. They were easily distinguished from the small bundles occurring in the sclerenchyma tissue at the outer edge of the culm (Figures 2 to 7).

The number of bundles in the second and third internodes did not differ significantly from each other. However, they differed from the number found in the first internode. It was apparent that the number of bundles per variety remained much more constant at the second and third internodes when different culms were sectioned. Again, there seemed to be less variability at the second internode than at the third. It may be of significance that this same internode was chosen previously for the interpretation of field studies.

In comparing varieties the weak strawed varieties had a low number of vascular bundles while the strong strawed varieties had a high number. The differences were highly significant. There was no significant difference in the number of vascular bundles between the two strong varieties Ardri and Acton. Likewise, the weak strawed varieties did not differ from each

other in number of bundles. This character was the only one to show interaction between varieties × positions. The interaction was significant but not highly so, indicating that the differences between the varieties were changed to a certain extent by the positions. This could be explained by examining the values for the first and second internodes. The number of bundles for the variety Acton in the first internode was almost as low as that for Don de Dieu, while in the second internode it was much higher. This would contribute to the interaction. Variability in number of vascular bundles was apparent when counts were being made on sections from the first internode. This emphasizes the necessity of taking measurements at the second or third internodes in order to show where the main differences lie. The second internode may be preferred. The difference in number of vascular bundles between strong and weak strawed varieties was the most clear cut character difference studied. If, after further investigation, this relationship can be found to remain constant, then it will offer distinct possibilities as a criterion of culm strength.

K—*Number of Vascular Bundles in Sclerenchyma Layer of Culm*

The number of vascular bundles which were situated near the outer boundaries of the culm did not vary significantly from variety to variety or from internode to internode. *F* values for this character were insignificant.

L—*Ratio of Width of Sclerenchyma Layer to Width of Culm Wall*

The ratio of width of the sclerenchyma layer to the width of the culm wall was determined primarily to ascertain if there was any association between the relative amount of sclerenchyma tissue and the differences in percentage lignin found between the weak and strong varieties. No significant differences were found to exist between varieties or between internodes, for this ratio. There was an interaction between varieties and positions indicating that the differences between varieties vary with a particular internode.

The study of the internodal anatomy of oat culms illustrated that varieties differed in the extent to which the tissues, cells and vascular bundles develop. Many differences also existed between culm internodes of a variety. For many characters studied these differences were not in the order of the straw strength of the four varieties. However, the radial diameter of the vascular bundles in the parenchyma area of the culm and the number of vascular bundles in the same region did differ significantly between the strong and the weak varieties. These differences were very distinct, especially in the second and third culm internodes.

FIGURES 4 AND 5. Portions of microtome cross-sections which represent the centre of the second internode of the culm. Don de Dieu (A) and Old Island Black (C) which are susceptible to lodging, each have 31 vascular bundles in the parenchymatous area of the culm. Acton (B) and Glasnevin Ardri (D), which are resistant to lodging have 40 and 39 vascular bundles respectively. The latter also have larger vascular bundles than do the weak strawed varieties. Differences in culm wall thickness are not as great at this internode. No other varietal characteristics appear to be definitely associated with lodging. Part of the leaf sheath is present in C. ×82.

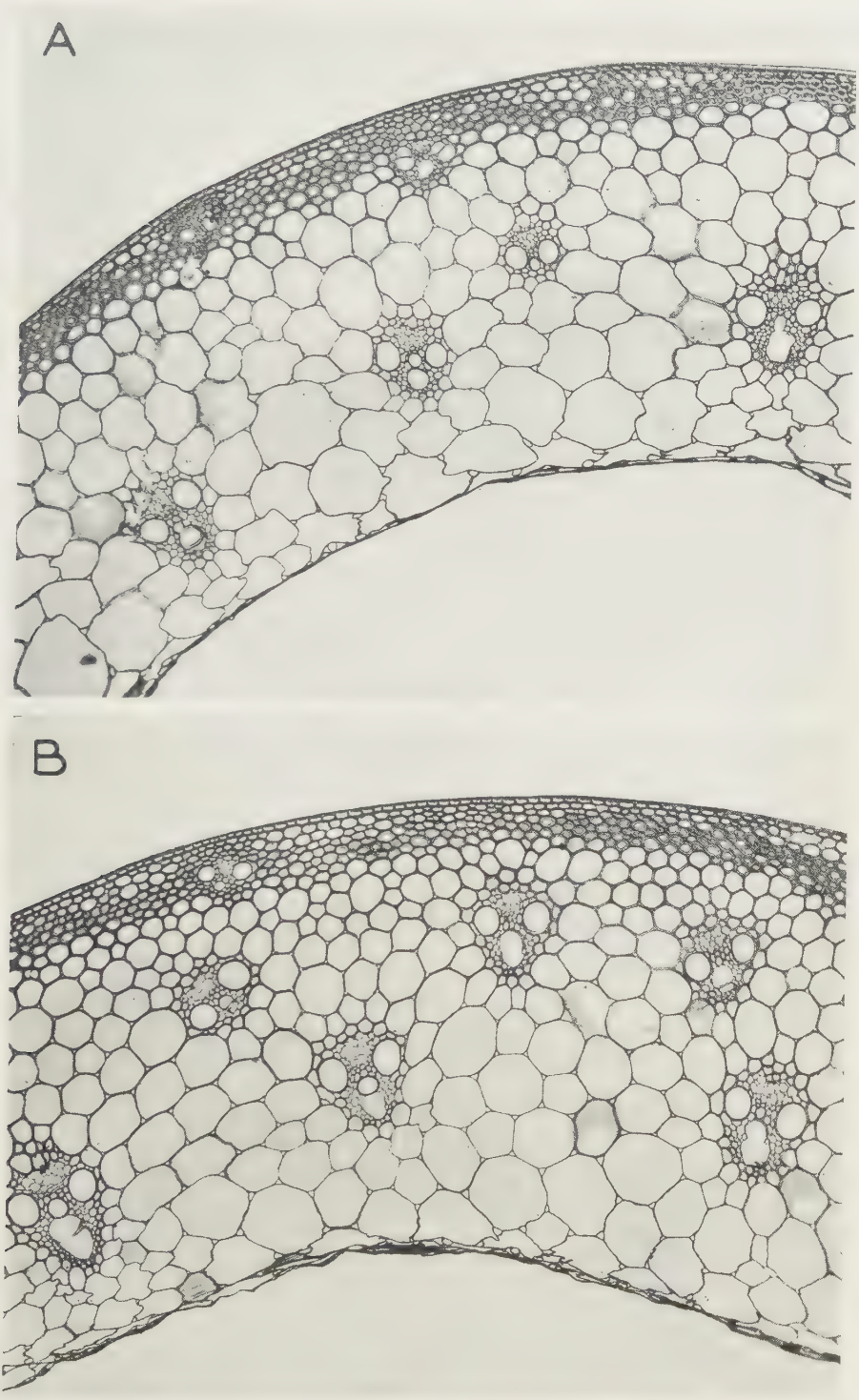

FIGURE 4.

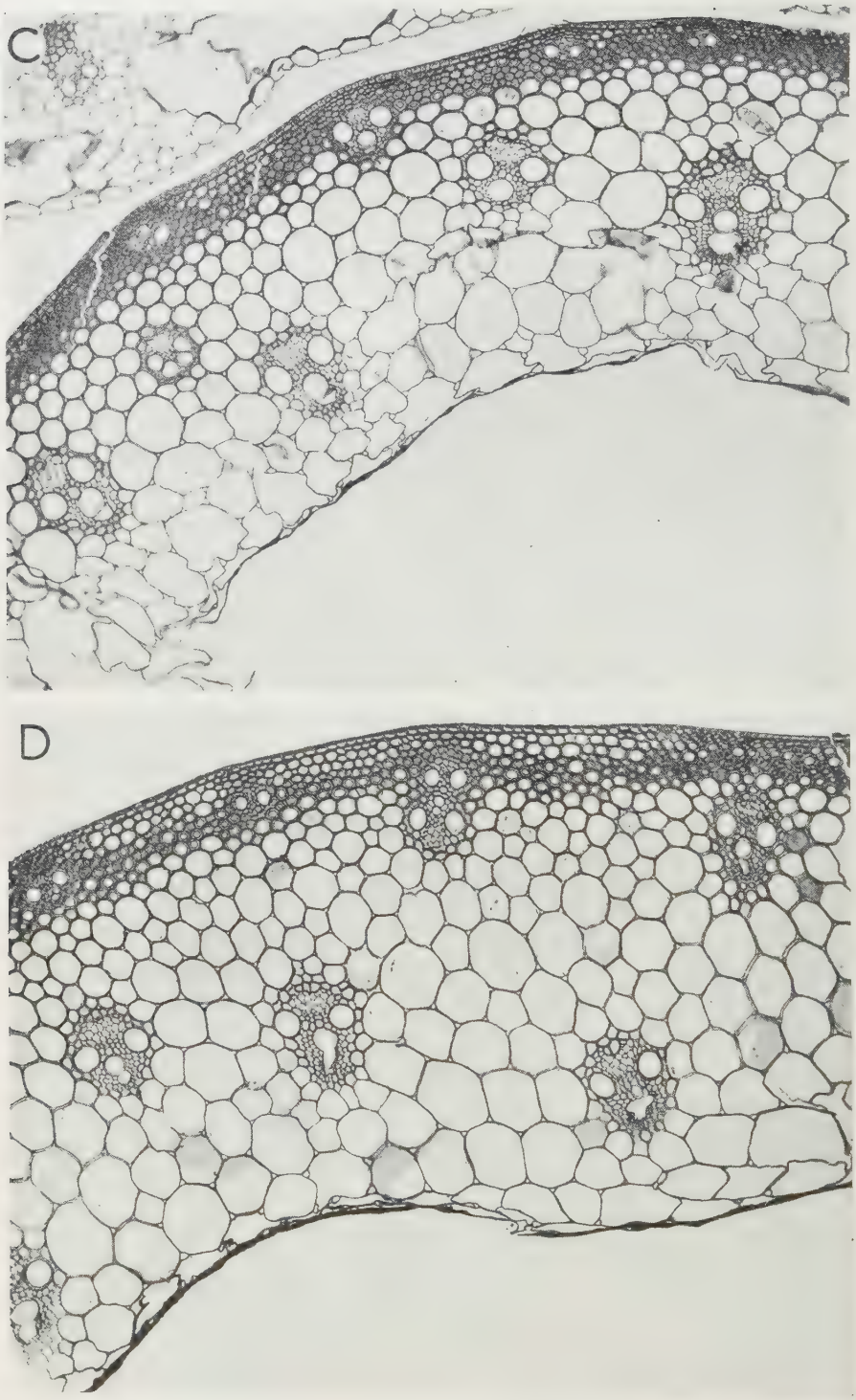

FIGURE 5.

DISCUSSION

The culm characters of several oat varieties, which range from one extreme to another in ability to remain upright throughout the growing season, have been under investigation for a period of over two years. External plant measurements, chemical determinations and internal culm anatomy have been studied in an attempt to locate some character or association of characters which might act as a criterion when applied to the strength of straw of the different varieties. Culm measurements were largely confined to the lower three internodes above ground. Many characters studied offered no apparent possibilities as an index to lodging, while with other characters definite relationships have been found to exist.

The number of nodes per plant varied greatly within any one variety and between varieties. No relationship could be established between the number of nodes per plant of a variety and percentage lodging. No association could be found between straw strength and the length of the culm internodes. Likewise, the length of leaf sheath appeared to be of no significance. The measurements at the second internode above ground were selected for detailed study in the case of culm diameter and thickness of the culm wall.

By analysis of variance for both years, the various effects of the following culm measurements on lodging were determined: (1) height of main tillers, (2) diameter of culm at second internode, (3) thickness of culm wall at second internode, (4) weight per unit length of culm, and (5) percentage dry matter. Height of main tillers and diameter of culm presented a more consistent relationship to lodging than did the other three characters. That taller plants are associated with a high degree of lodging was indicated. Stronger varieties had culms with greater diameters, particularly at the second internode. Thin culm walls seemed to predispose a plant to lodging although this relationship was not too evident. The varieties which lodge tended to have a low weight per unit length of culm. This was true for certain varieties but did not appear to be the case for all varieties. The relationship of dry matter to lodging, although varying greatly tended to be significant in only one year, there was a greater amount of dry matter in lodged grain rather than any deficiency of it.

The multiple correlations for both years, measuring the total effect of the above five characters on lodging did not show a significant relationship. For both years height of main tillers and diameter of culm have been shown by analysis of variance to contribute, by far, the greater part of the relationship to lodging. Thickness of culm wall, weight per unit length of culm and percentage dry matter appeared to express no significant relationship to lodging above that already expressed by height and diameter of culm. Depending upon the varying environmental effects as they influence lodging, the results of a single year may not always show height and diameter of culm to be both significantly correlated with lodging. This was the case in 1938. Rather it was the importance of the combined effect of the two characters which was emphasized. The other three measurements were much more difficult to determine and more personal error was involved, especially in measuring the culm wall thickness. The value of these characters as an index to lodging is probably not great. The ease

with which height of plants and diameter of the culm at the second internode can be determined together with the high degree of association with lodging seems to point to the combined measurement of the two as having distinct possibilities as a criterion of lodging.

If, for each variety, the average height of the main tillers is divided by one tenth the diameter of the culm, an index figure is obtained. In general, it follows the percentage lodging. Such an index figure together with the lodging data and the correlations between the two for 1938 and 1939 appears in Table 10.

TABLE 10.—POSSIBLE INDEX FIGURES FOR PERCENTAGE LODGING

Variety	Possible index	Percentage lodging	Variety	Possible index	Percentage lodging
1938			1939		
Trelle's Dwarf	50.5	0	Trelle's Dwarf	64.5	0
Eagle	67.9	9	Eagle	84.8	11.8
Great Mogul	76.1	9	Acton	98.9	15.0
Waterloo	80.0	9	Laurel	86.1	15.0
Acton	86.8	10	Great Mogul	98.7	29.5
Victory	89.8	30	Victory	99.8	41.8
White Cross	89.2	35	Waterloo	87.2	47.7
C.D. 1625	96.5	40	White Cross	95.5	55.2
Don de Dieu	104.9	99	Don de Dieu	114.1	98.2
Old Island Black	100.7	99	Old Island Black	123.1	98.2
Correlation coefficient $r = +0.793$			Correlation coefficient $r = +0.846$		

NOTE—r at 5% level of significance and 8 degrees of freedom = 0.632.

In Table 10, for example, both a tall plant and a thin culm favoured lodging and, at the same time, tended to increase the index number. Such figures may suggest, that after further study a lodging index can be developed. Determining the number of vascular bundles may aid in so doing. The correlations between the index figures and degrees of lodging were found to be significant. While the latter reaches a maximum of 100%, the index has no such maximum. Hence, at about 100% lodging, the two sets of values come together. More than two years' results are needed before a lodging index can be established.

Certain chemical determinations made on the three lower culm internodes bore out the relationship of lignin to lodging. While it was not distinct for each and every variety, there existed a definite association between high percentage lignin and high percentage lodging. Likewise, low percentage lignin and low percentage lodging tended to go together.

FIGURES 6 AND 7. Portions of microtome cross-sections which represent the centre of the third internode of the culm. Of the weak strawed varieties, Don de Dieu (A) has 33 vascular bundles and Old Island Black (C) has 35. Of the strong-strawed varieties, Acton (B) has 37 vascular bundles and Glasnevin Ardri (D) has 40. The vascular bundles in the culms of the lodging resistant varieties are greater in size than the vascular bundles in the varieties susceptible to lodging. Differences in thickness of culm wall are not great. Only the number and size of vascular bundles show a distinct relationship to lodging behaviour. ×82.

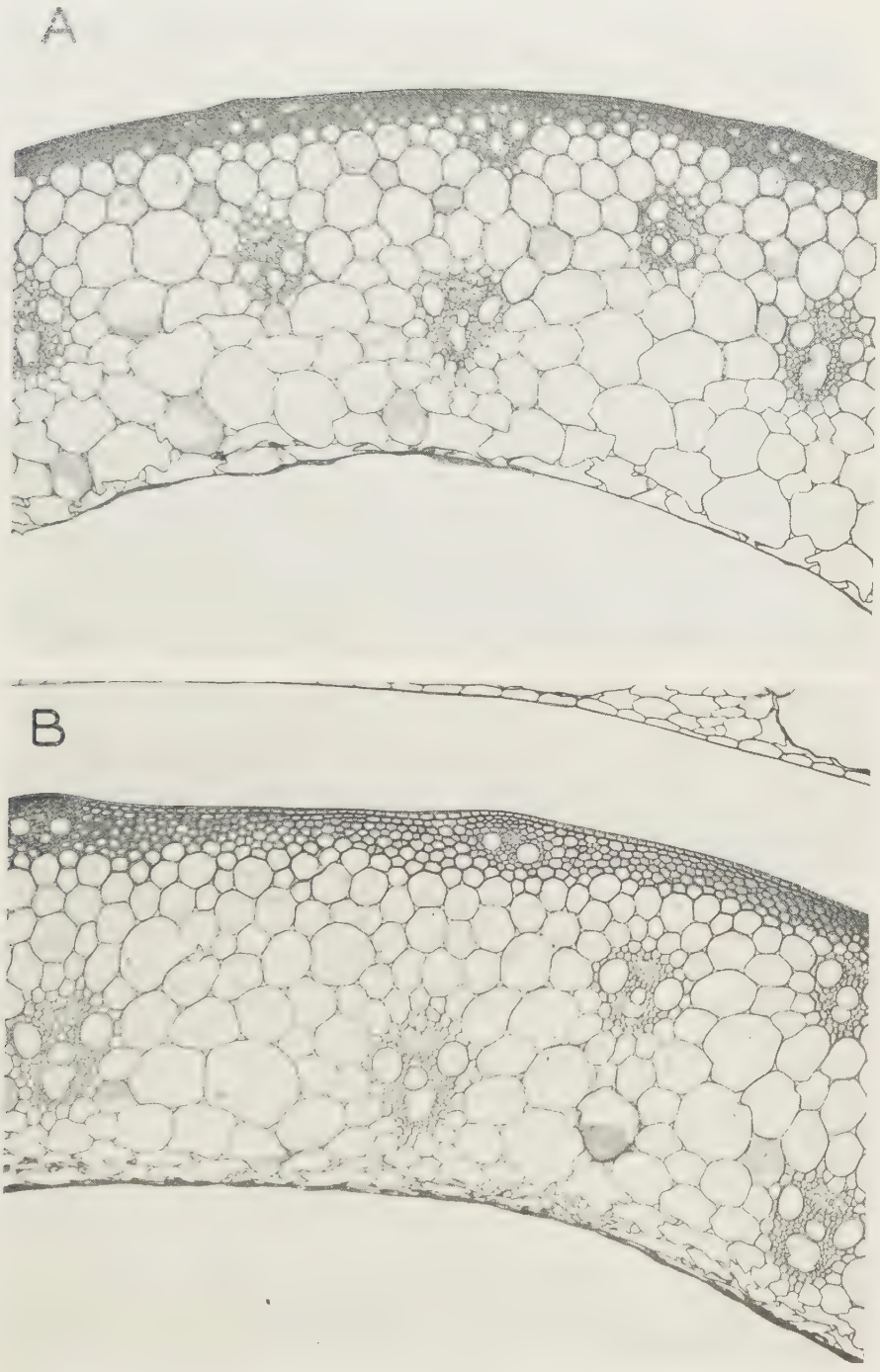

FIGURE 6.

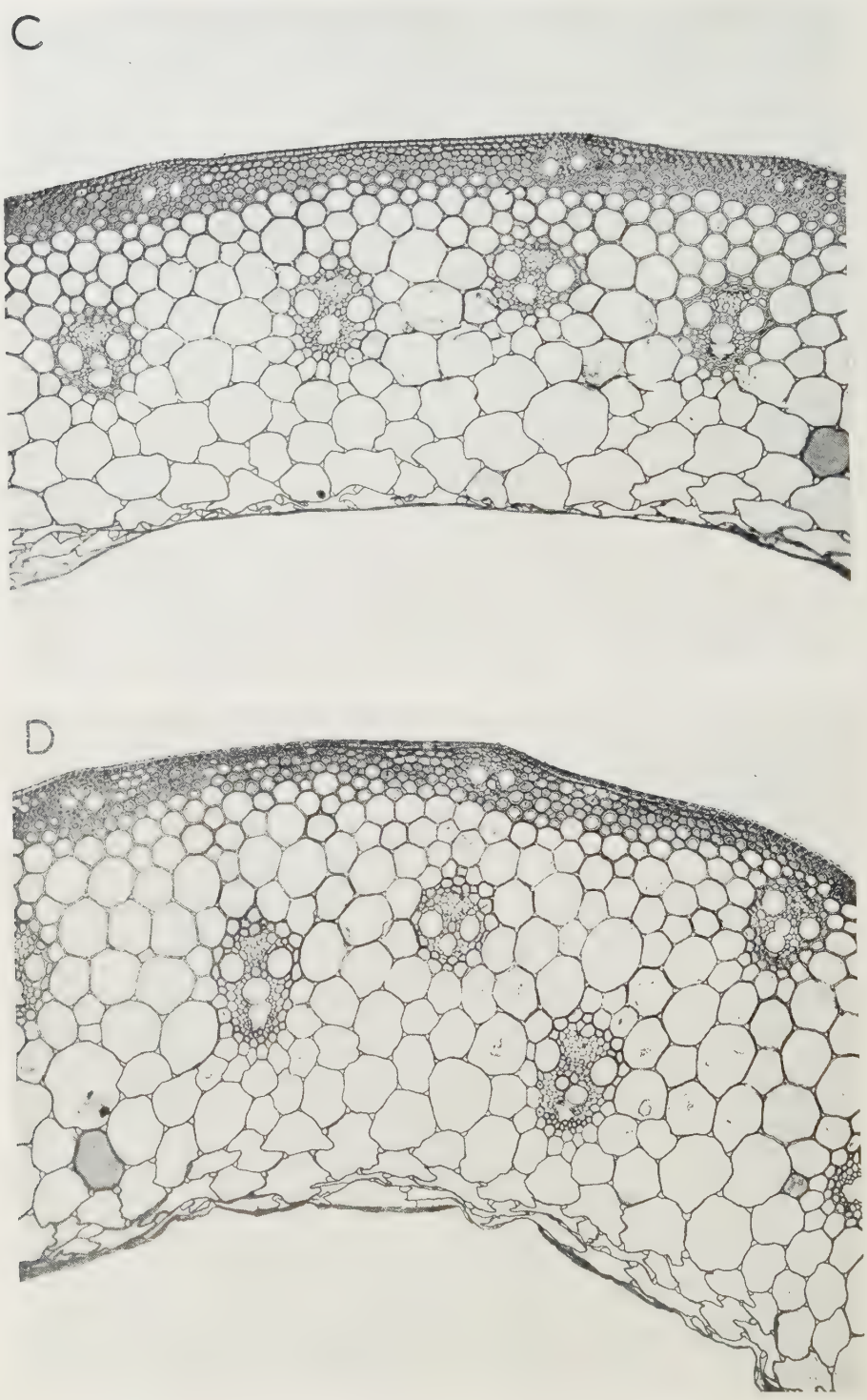

FIGURE 7.

This relationship was of interest and especially since lignin has often been thought of as contributing to strength of straw rather than the reverse. It may be that a high percentage of lignin tended to make the culms more brittle. The lignin figures, when analyzed with height of main tiller and diameter of culm showed that percentage lignin can express only a very small effect on lodging above that already explained by height and diameter of culm. This further emphasized the importance of height of plants and diameter of culm as a possible lodging index.

Percentage sand (insoluble in acid or alkali) and percentage lodging were not correlated. Percentage silica (alkali soluble) was positively correlated with lodging in only one year. These results substantiated the previous conception that silica is too variable a substance in the plant to have a direct bearing on lodging. Lodging was not found to be correlated with percentage pentosans.

Histological studies brought out the fact that different oat varieties differ in the development of several anatomical characters. For many characters, these differences were not in the order of the strength of straw of the different varieties and were of no value as foretellers of lodging behaviour. The results pointed out that culm characters may differ from one internode to another. From these studies it would seem preferable to use the second above-ground internode for all comparative culm measurements.

Varietal differences in width of sclerenchyma layer were not in the order of percentage lodging. Likewise, width of the culm wall did not separate the varieties according to their lodging behaviour. Diameter of the hollow centre of the culm did not indicate the straw strength of a variety. The number of cell layers of sclerenchyma tissue, while more definitely associated with percentage lodging than the anatomical characters already mentioned, was probably not to be valued as an index. The radial diameter of the vascular bundles was relatively constant for all internodes. At the same time the vascular bundles of the strong strawed varieties, used in this study, had a greater radial diameter than had the bundles in varieties with weak straw. This character, while not altogether a practical index to apply, was of value in showing where relationships lie. Width of vascular bundles did not show a clear cut relationship to lodging. The above results suggested that strong strawed oat varieties have larger vascular bundles than weak strawed varieties.

Varieties differed in the number of lignified cells in the bundle sheath but these differences were not necessarily associated with weak and strong straw. Likewise, the number of lignified cells inside the bundles added no valuable information in relation to lodging. The number of small vascular bundles in the outer culm area and the ratio of the width of sclerenchyma tissue to the width of the culm wall did not seem to be of any importance in solving this problem.

The number of vascular bundles situated in the parenchyma area of the culm was distinctly greater in the strong strawed types than in the weak strawed types. The differences were more definite at the second and third culm internodes. This character would seem to have greater possibilities as an index to lodging.

The Possibilities of Establishing a Lodging Index

Many plant characters, no doubt, exert an influence directly or indirectly in determining whether or not a variety will have strength of straw or weakness of straw. The effect of certain characters may be very small, variable, and difficult to evaluate. Other culm characters appear to present quite definite relationships to lodging. To apply such relationships an index will necessarily have to be developed to make use of the results in a practical program. Certain influences may be of an additive nature as in the case of height and culm diameter. In some instances the relationship of a certain character to lodging may be equally as well expressed by some other character as was the effect of lignin expressed in some duplicate manner by height and culm diameter.

Before an index to lodging can be put forth it will probably be necessary to have a definite position in the culm at which to make measurements. The second internode above ground seems a logical location. Results at present indicate that the culm characters offering possibilities on which to base an index to lodging, are, height of plants together with the culm diameter at the second internode above the ground, size and number of vascular bundles at the second or third internodes, and possibly percentage lignin. The reliability of any criterion to lodging behaviour will have to be tested under different environments.

Since heavy storms cause many plants to lodge at the ground level, a thorough comparison of crown and root growths of different varieties will eventually be necessary. This fact has been pointed out by various workers.

SUMMARY

1. The number of nodes per plant showed no relationship to lodging.

2. The length of the three lower culm internodes was not associated with strength of straw.

3. Lodging was not influenced by the length of the three lower leaf sheaths.

4. The combined effect of height of plant and diameter of the culm at the second above-ground internode presented a definite relationship to lodging.

5. Thickness of culm wall at the second internode, weight per unit length of culm and percentage dry matter may in certain years be correlated with percentage lodging. They presented no significant relationships above those already explained by height and diameter of culm.

6. A high degree of lodging tended to be associated with a high percentage of lignin or vice versa.

7. Percentage silica (alkali soluble) offered no possibilities as an index to lodging.

8. Percentage sand (insoluble in acid or alkali) showed no relationship to lodging.

9. Percentage of pentosans and percentage lodging were not correlated.

10. The following anatomical characters of the culm were not regarded as possible lodging indices: *(a)* width of sclerenchyma layer; *(b)* width of the culm wall; *(c)* diameter of the hollow centre of the culm; *(d)* number of cell layers of sclerenchyma tissue; *(e)* width of vascular bundles; *(f)* number of lignified cells in the bundle sheath; *(g)* number of lignified cells inside the bundles; *(h)* number of vascular bundles near the outer edge of the culm; *(i)* ratio of the width of the sclerenchyma tissue to the width of the culm wall.

11. Radial diameter of vascular bundles was significantly greater in strong strawed varieties than in weak strawed varieties.

12. The number of vascular bundles in the parenchyma area of the culm was much greater in strong strawed varieties than in weak strawed varieties.

13. The development of certain culm characters may vary from internode to internode. The second culm internode appeared to be the position where comparative differences between varieties are more likely to remain constant.

14. Present results indicated that a possible index to lodging can be most reliably based on the following characters: height of plants together with the diameter of the culm at the second internode; size and number of vascular bundles; also preferably at the second internode; and probably percentage lignin.

ACKNOWLEDGMENT

The writer is very grateful to Mr. R. A. Derick, Senior Assistant Cerealist, Central Experimental Farm, Ottawa, for suggesting the problem and guiding the first two years of the work; to Dr. J. G. Dickson, Prof. of Plant Pathology and Agent in Cereal Investigations, University of Wisconsin, under whose direction the study was continued; to Dr. J. H. Torrie, Dept. of Agronomy, for guiding the statistical analysis of the data; to Dr. J. C. Woodward, Chemistry Division, Ottawa, for supervising the chemical analyses; and to Mr. Eugene Herrling for taking the photomicrographs.

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BOOK REVIEW

"Farm Animals: Their Breeding, Growth and Inheritance" by John Hammond, M.A., D.Sc. (Iowa), F.R.S.; 199 pages with 114 Figures, 11 Tables and selected bibliography. Edward Arnold & Co., London, 1940; Longmans, Green & Co., Toronto 2, Canada (Price $4.25).

Dr. Hammond of the School of Agriculture, Cambridge University, is well known for his works on the physiology of reproduction and growth (differential development) in farm and laboratory animals. This book, to quote the preface, "is based on two series of lectures which were given to inform the student and animal breeder of some of the results of recent scientific research and its application to the practical problems of live stock production."

The book is profusely and excellently illustrated with photographs, charts and tables, which, together with the bibliographies, author and subject index, take up fully one-half of the 199 pages. In style it is somewhat didactic (being based on lectures) and very concise rather than of the more monographic style of literature survey.

It is divided into two parts. The first, "Fertility and Growth in Farm Animals" gives a brief but excellent account of all phases of reproduction and differential growth, a chapter being devoted to each class of farm animals, including poultry. Part II contains five chapters and is devoted to "Genetics in Relation to the Practical Problems of Breeding Farm Animals". This is a difficult subject for successful exposition and while it is well written, the 64 pages devoted to it are hardly sufficient for adequate treatment.

Naturally, very few technical details are given. The book would be very useful to students of animal breeding. To the non-specialist too it presents a readable survey of the scientific aspects and problems of animal breeding.

ALAN DEAKIN.